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RESPONSES OF SOME PLANTS TO EQUAL AND UNEQUAL RATIOS OF LIGHT AND DARKNESS IN CYCLES RANGING FROM 1 HOUR TO 72 HOURS [1]

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INTRODUCTION

During the longer days of summer and in high latitudes it is a comparatively simple matter to study the length-of-day behavior of plants under the normal daylight of the natural 24-hour cycle. This can be done by the use of dark houses excluding all light, in which the plants can be kept when the daily number of hours of daylight allowed in the test each day has been satisfied. When cycles longer or shorter than the natural length of day of 24 hours are desired, the use of natural daylight supplemented with artificial light or artificial light alone must be resorted to. In the experiments now being reported upon, artificial light alone was used together with fairly constant temperature and humidity.

In the literature [2] [3] [4] [5] [6] there has been much more work reported that dealt with the natural-day cycle of 24 hours than with longer or shorter cycles, partly because specially designed and expensive equipment is required to obtain sufficiently high light intensity without excessive heating, together with accurate and dependable regulation of the desired light and darkness periods. In addition to this, control of temperature and humidity within fairly narrow limits becomes a part of the problem of the artificial climate proposed.

For this reason it has been thought desirable to present the following data for comparison with previously accumulated data based upon the same ratios in the natural-day cycle of 24 hours.[7]

MATERIAL AND METHODS

Control of ventilation, temperature, and humidity was obtained by the use of a vertical-type unit air conditioner, so adapted as to carry modified air through suitable ducts at a constant rate into eight plant cabinets, each about 19 inches square.

[1] Received for publication March 31, 1941.

[2] GARNER, W. W., and ALLARD, H. A. EFFECT OF ABNORMALLY LONG AND SHORT ALTERNATIONS OF LIGHT AND DARKNESS ON GROWTH AND DEVELOPMENT OF PLANTS. Jour. Agr. Res. 42: 629–651, illus. 1931.

[3] MCALISTER, E. D. TIME COURSE OF PHOTOSYNTHESIS FOR A HIGHER PLANT. Smithsn. Inst. Misc. Collect. 95, No. 24, 17 pp., illus. 1937.

[4] IGGENA, MARIE LUISE. BEOBACHTUNGEN ÜBER DIE WIRKUNG DES LICHTES AUF DAS WACHSTUM VON BLAUALGEN UND GRÜNALGEN. Arch. f. Mikrobiol. 9: [129]–166, illus. 1938.

[5] AUFDEMGARTEN, HEINRICH. ZUR KENNTNIS DER SOGENANNTEN INDUKTIONSVORGÄNGE BEI DER KOHLENSÄUREASSIMILATION. Planta 29: 643–678, illus. 1939.

[6] HAMNER, KARL C. INTERRELATION OF LIGHT AND DARKNESS IN PHOTOPERIODIC INDUCTION. Bot. Gaz. 101: 658–687, illus. 1940.

[7] The term "cycle," as here used, refers to the time elapsing from the beginning of one light interval to another. It includes an interval of light together with the interval of darkness immediately following. In a 1 : 1 ratio of light and darkness, an alternation of 12 hours of light with 12 hours of darkness constitutes a cycle of 24 hours.

The light in each cabinet was furnished by a specially manufactured water-jacketed and water-cooled 110-volt 1,000-watt incandescent bulb equipped with reflector, giving at a distance of 1 foot below the bowl an intensity of about 1,200 foot-candles as measured by a Weston illumination meter, model 603, equipped with a viscor filter to measure only visible radiation.

The plants were grown in porcelain sauce pots of 8-gallon capacity, 15.5 inches in diameter and 11.7 inches high, and without drainage holes at the bottom. Each cabinet held one pot.

The soil used was a well-screened, well-mixed greenhouse loam. Nine pounds of clean river sand was first leveled on the bottom of each pot, which was then filled with 85 pounds of packed soil, so that the amount of soil and sand was the same in each.

The soil placed in the cans was at the optimum tilth, the moisture content determined at this time being 19 to 20 percent.

Except in the case of *Rudbeckia bicolor*, which was first sown in flats, the seeds were sown in the containers in the warm greenhouse, and promptly at germination the seedlings were transferred to the tests. Throughout all tests temperature was maintained at 77° F., plus or minus 2°, with a humidity of 60 percent, plus or minus 2 percent.

The pots rested upon counterpoised balances in the cabinets, and the water loss was compensated for by the addition of distilled water each day.

The plants used were Peking soybean (*Soja max* (L.) Piper), a plant whose flowering is hastened by short days; *Rudbeckia bicolor* Nutt., a plant whose flowering is more favored by long days; *Zinnia angustifolia* H. B. K.(sold in the trade under the name *Z. mexicana* Hort.), a plant strictly indeterminate or day-neutral in its responses; wheat (*Triticum aestivum* L.), spring wheat variety Hard Federation, which appears to be a long-day, high-temperature type; and dill (*Anethum graveolens* L.), an umbellifer of long-day habit with respect to flowering.

In some instances a definite cycle of light and darkness was adopted, and a study of different ratios of light to darkness was made. In other instances attention was directed mainly to equal ratios of light and darkness involving total light-darkness cycles ranging from only 1 hour to as much as 72 hours. In all tests a control set was grown with alternations of 12 hours of light and darkness, to serve as the standard of behavior for the natural 24-hour cycle, which most plants experience everywhere in nature except at or near the poles, where continuous light prevails during the growing season.

EXPERIMENTAL DATA AND DISCUSSION

PEKING SOYBEAN

From the data on the Peking soybean in table 1, it is obvious that the plants grown in cabinets 1 and 2, experiencing equal alternations of light and darkness in cycles of 24 and 18 hours respectively, differed markedly in growth and behavior even though for the entire period of the experiment the total duration of illumination was the same. The 9-hour alternation somewhat delayed flowering, greatly reduced the yield of beans, increased the size of the leaves, as well as the height of the plants, and decreased the dry weight. It would appear that the shorter alternations of the 18-hour cycle tended to delay and reduce flowering, to that extent being less favorable to reproductive expres-

sion. Thus it would seem that this alternation and cycle tend toward an intensification of the long-day influence.

In cabinets 3, 4, and 5, with light periods of 4½, 6, and 7½ hours, respectively, in an 18-hour cycle corresponding to short days of 6, 8, and 10 hours in the 24-hour cycle of natural day, flowering was induced as it is when Peking soybean experiences corresponding lengths of day in these same ratios in the longer natural cycle.

When these ratios were reversed, as in cabinets 6, 7, and 8, so that the light periods were 10½, 12, and 13½ hours, corresponding to 14, 16, and 18 hours of the natural 24-hour cycle, flowering was inhibited for the entire course of the experiment. These plants consistently increased in height, dry weight, and size of leaf, as the proportion of light was increased.

It is interesting to note that the leaves grew very thick and heavy in the two cabinets (1 and 2) that received equal ratios of light and darkness, i. e., 12-hour and 9-hour alternations respectively, and that

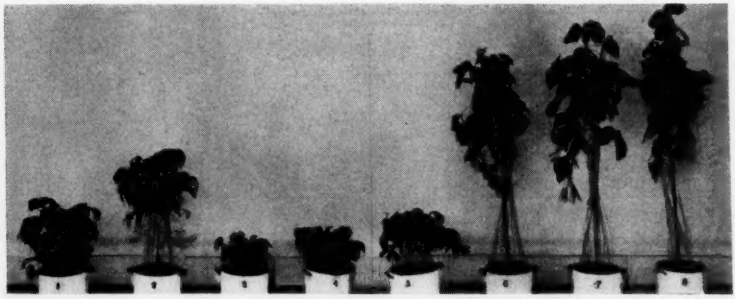

FIGURE 1.—Peking soybean (*Soja max*) grown under artificial light, with various ratios of light and darkness in cycles of 18 and 24 hours. Seed sown February 19, 1935; tests begun February 23, at germination. Plants photographed April 23, when tests ended. Numbers on pots correspond to designations of test cabinets.

1, 12 hours light; 12 hours dark. Buds March 13; flowered March 18 at 11 inches.

2, 9 hours light; 9 hours dark. Buds March 18; flowered March 22 at 17 inches.

3, 4½ hours light; 13½ hours dark. Buds March 12; flowered March 16 at 6 inches.

4, 6 hours light; 12 hours dark. Buds March 12; flowered March 16 at 7 inches.

5, 7½ hours light; 10½ hours dark. Buds March 12; flowered March 15 at 8 inches.

6, 10½ hours light; 7½ hours dark. Never budded; height when photographed, 72 inches.

7, 12 hours light; 6 hours dark. Never budded; height when photographed, 77 inches.

8, 13½ hours light; 4½ hours dark. Never budded; height when photographed, 85 inches.

the foliage developed the same degree of greenness. In cabinets 3, 4, and 5, receiving increasing proportions of light, namely 4½, 6, and 7½ hours, respectively, the leaves developed increasingly darker greenness and the dimensions of the leaves were likewise augmented.

With respect to the nutrition of the plants and the production of dry matter, it is obvious that increase in the hours of light, regardless of the ratio of light to darkness, resulted in improved growth. The time of flowering, on the other hand, was more affected by the ratio of light to darkness and the length of the cycle (fig. 1).

TABLE 1.—*Flowering dates, heights, green and dry weights, and other data for Peking soybean grown in an 18-hour cycle* [1]

Cabinet No.	Light period	Dark period	Buds [2]	First flowers	Height of plants at—		Weight of—						Mean dimensions of terminal leaflets of 5 leaves		Leaf color and other data at end of test
					Flowering	End of test	Tops		Roots		Total tops and roots				
							Green	Air-dry	Green	Air-dry	Green	Air-dry	Length	Width	
	Hours	*Hours*			*Inches*	*Inches*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Inches*	*Inches*	
1 (check)	12	12	Mar. 13	Mar. 18	11	21	548.6	135.4	21.2	6.0	569.8	141.4	5.45	3.2	Dark green; yield of pods high; leaves thick and heavy.[3]
2	9	9	Mar. 18	Mar. 22	17	37	598.4	114.0	30.8	7.8	629.2	121.8	6.25	4.15	Color as in 1, but yield much less; leaves very heavy, thicker than in 1.
3	4½	13½	Mar. 12	Mar. 16	6	12	155.5	34.6	4.9	.8	160.4	35.4	4.45	2.4	Lightest green of all the tests; low yield of pods; leaves thinnest of all in tests.
4	6	12	do	do	7	14.5	295.5	76.3	17.6	4.0	313.1	80.3	4.2	2.45	Darker green than in 3, but not as dark green as in 1; yield of pods greater than in 3 and leaves thicker.
5	7½	10½	do	Mar. 15	8	19.5	370.0	89.4	19.6	4.8	389.6	94.2	5.2	3.05	About as dark green as in 4; very prolific in pods, approaching 1; leaves not as thick as in 4.
6	10½	7½	None	None		72	571.0	107.9	29.2	6.9	600.2	114.8	6.1	4.2	Not as dark green as in 1 or 2; leaves thin.
7	12	6	do	do		77	936.5	145.3	39.1	8.7	975.6	154.0	7.45	5.1	About as dark green as in 6, and leaves about as thin.
8	13½	4½	do	do		85	1,116.2	187.9	59.9	11.9	1,176.1	199.8	8.05	5.5	Darker green than in 7; leaves about as thin and growth better.

[1] Tests began Feb. 23, 1935, at germination, and ended Apr. 23; 12 plants in each pot, planted in a circle about 2 inches from the periphery.
[2] Externally visible buds have been considered; no microscopic examination was made in those tests where flowering did not take place.
[3] Plants in cabinets 1 and 2 had leaves so thick that they broke readily when folded and pressed between the fingers, as does a mature tobacco leaf; they appeared to be packed with starch.

TABLE 2.—*Flowering dates, heights, green and dry weights, and other data for Peking soybean grown in a 36-hour cycle* [1]

Cabinet No.	Light period	Dark period	Buds	First flowers	Height of plants at—		Weight of—						Mean dimensions of terminal leaflets of 5 leaves		Leaf color and other data at end of test [2]
					Flowering	End of test	Tops		Roots		Total tops and roots				
							Green	Air-dry	Green	Air-dry	Green	Air-dry	Length	Width	
	Hours	*Hours*			*Inches*	*Inches*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Inches*	*Inches*	
1	9	27	Jan. 15	Jan. 18	9	11	98.8	18.1	4.0	0.8	102.8	18.9	2.75	1.50	Distinctly yellowish green; spindling, etiolated.
2	12	24	Jan. 18	Jan. 21	11	25	272.6	44.5	10.3	1.9	282.9	46.4	4.0	2.25	Slightly darker green than in 1.
3	15	21	Feb. 8	Feb. 12	29	39	431.6	71.0	19.6	4.0	451.2	75.0	5.25	3.00	Slightly darker green than in 2.
4	18	18	None	None		51	569.4	102.4	24.0	5.2	593.4	107.6	6.00	3.75	Slightly darker green than in 3.
5	21	15	do	do		48	619.0	98.1	25.5	5.6	644.5	103.7	6.00	3.75	Nearly normal green, darker than in 3.
6	24	12	do	do		62	802.8	126.1	27.9	5.8	830.7	131.9	7.25	4.75	Dark green, darker than in 4; stocky, leafy plants.
7	27	9	do	do		72	957.5	159.1	23.9	5.7	981.4	164.8	6.00	4.50	Very slightly darker than in 6; stocky, leafy plants.
8 (check)	12	12	Jan. 8	Jan. 10	11½	19	297.0	86.1	26.8	5.8	323.8	91.9	4.00	2.25	About as dark green as in 7; stocky, leafy plants.

[1] Tests began Dec. 18, 1934, at germination, and ended Feb. 18, 1935; 12 plants in each pot, planted in a circle about 2 inches from the periphery.

[2] Plants in cabinet 1 very slender and sickly. Gradual improvement shown in color and leafiness in cabinets 2, 3, 4, and 5. Plants in cabinet 5 showed evidences of slight etiolation and lack of vigor.

If the effects of equal alternations of light and darkness in a 24-hour cycle are compared with those in a 36-hour cycle (table 2), it will be noted that alternations of 18 hours of light and darkness inhibited flowering for the duration of the experiment. These plants continued to grow, reaching a height of 51 inches as compared with 19 inches for the plants receiving the 12-hour alternations, and were not as dark green as the latter. The dry weight of tops and roots of the plants in cabinet 4 somewhat exceeded the dry weight of those in cabinet 8.

In cabinets 1, 2, and 3, where light intervals were 9, 12, and 15 hours, respectively, in the ratios to darkness of 1:3, 1:2 and 1:1.4, corresponding to short days of 6, 8, and 10 hours on the basis of the natural 24-hour cycle, all the plants flowered, but with increasing delay as compared with the control plants receiving 12-hour alternations of light and darkness. With an increase in the ratio of light to darkness from 1:2 to 1:1.4 (cabinets 2 and 3), the period from germination to flowering increased from 34 to 56 days. This was attended by a marked increase in height, dry weight of plants, and size of leaves. This finding is of considerable interest, since these light durations correspond to very short days for the natural 24-hour cycle, i. e., days of 8 and 10 hours, both of which in this cycle cause earliest flowering in the Peking soybean and many other short-day plants. It would appear that with 15 hours of light in the 36-hour cycle the plants tend toward vegetative expression with retardation of flowering and consequent increase in the purely vegetative functions.

With the increase in the duration of the light intervals in the cycle of 36 hours, namely, 9, 12, 15, and 18 hours, respectively (cabinets 1 to 4), in ratios of 1:3, 1:2, 1:1.4, and 1:1, there was a gradual intensifying of the leaf green.

The plants in cabinets 5, 6, and 7 became more stocky and a darker green with increase in light intervals (21, 24, and 27 hours) in the same cycle of 36 hours, the intervals of light being longer than those of darkness and corresponding respectively to day lengths of 14, 16, and 18 hours in the 24-hour cycle. This is a natural consequence of better nutrition afforded by the increased amounts of light in the cycle.

As in table 1, the data in table 2, dealing with a single cycle of 36 hours, indicate that with increase in the hours of light there usually was an increase in dry matter produced, but as in the previous test, the time of flowering was more affected by the ratio of light to darkness (fig. 2).

The data presented in table 3 show certain interesting relations. In cabinets 1, 6, and 8, each experiencing equal alternations of light and darkness but involving cycles of 28 hours, 14 hours, and the natural cycle of 24 hours, respectively, alternations of 7 hours of light and darkness failed to cause flowering, alternations of 14 hours caused flowering in 33 days, and alternations of 12 hours caused flowering in 20 days.

At the close of the experiment the plants experiencing 14-hour alternations of light and darkness had reached a height of 50 inches; those experiencing 7-hour and 12-hour alternations had reached a height of 70 inches and 21 inches respectively. Of these three alternations, the 12-hour alternation produced the greatest amount of dry

matter; the 14-hour alternation, somewhat less; and the 7-hour alternation, still less.

A peculiar feature of the development of greenness of the foliage was shown in response to the 14-hour alternation. At first the plants were decidedly yellowish green, but this was overcome gradually until finally the plants became dark green, apparently owing to some readjustment of the chlorophyll mechanism to these light periods, a behavior at present not understood. With the 12-hour alternation, the foliage developed a normal dark greenness from the outset, while the 7-hour alternation produced at all times a lighter green.

It would appear that the plants grown under the 7-hour alternation tended rather strongly toward vegetative development, with suppression of flowering and fruiting. There was a marked increase in

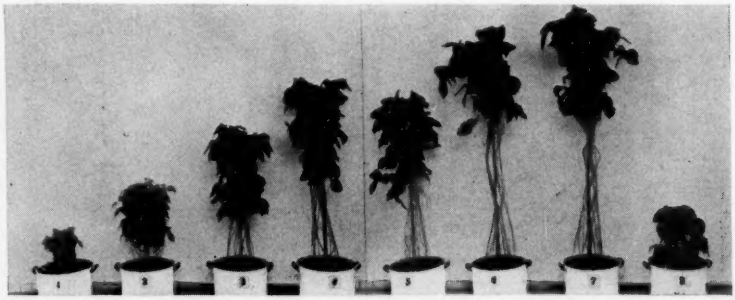

FIGURE 2.—Peking soybean (*Soja max*) grown under artificial light, with various ratios of light and darkness, in cycles of 24 and 36 hours. Seed sown December 14, 1934; tests begun December 18, at germination. Plants photographed February 18, 1935, when tests ended. Numbers on pots correspond to designations of test cabinets.

1, 9 hours light; 27 hours dark. Buds January 15; flowered January 18 at 9 inches.

2, 12 hours light; 24 hours dark. Buds January 18; flowered January 21 at 11 inches.

3, 15 hours light; 21 hours dark. Buds February 8; flowered February 12 at 29 inches.

4, 18 hours light; 18 hours dark. Never budded. Height when photographed, 51 inches.

5, 21 hours light; 15 hours dark. Never budded. Height when photographed, 48 inches.

6, 24 hours light; 12 hours dark. Never budded. Height when photographed, 62 inches.

7, 27 hours light; 9 hours dark. Never budded. Height when photographed, 72 inches.

8, 12 hours light; 12 hours dark. Buds January 8; flowered January 10 at 11½ inches.

height by continuance of growth although the dimensions of the leaves showed only slight differences.

As in the previous tests, there was an increase in dry matter as the hours of light in the 28-hour cycle increased from 7 to 9⅓, 11⅔, 14, 16⅓, and 21 hours respectively, but time of flowering, was more affected by the particular ratios of light and darkness and also by the length of the cycle (fig. 3).

TABLE 3.—*Flowering dates, heights, green and dry weights, and other data for Peking soybean grown in cycles of 14, 24, and 28 hours* [1]

Cabinet No.	Light period	Dark period	Buds	First flowers	Height of plants at—		Weight of—						Mean dimensions of terminal leaflets of 5 leaves		Leaf color and other data at end of test
							Tops		Roots		Total tops and roots				
					Flowering	End of test	Green	Air-dry	Green	Air-dry	Green	Air-dry	Length	Width	
	Hours	*Hours*			*Inches*	*Inches*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Inches*	*Inches*	
1	14	14	Feb. 8	Feb. 10	25	50	593	114	30	6	623	120	5.5	3	Dark green; at first decidedly yellowish green; fairly productive.
2	7	21	Jan. 28	Feb. 4	8	14	119	24	5	1	124	25	3.1	1.75	Very light yellowish green; fairly productive; plants sickly from the start.
3	9⅓	18⅔	do	Feb. 3	10	16½	246	53	10.5	2	256.5	55	3.8	2.3	Somewhat darker than in 2; very productive.
4	11⅔	16⅓	do	do	11	23	426	94	21	5	447	99	5.3	3.1	Dark green; very productive.
5	16⅓	11⅔	None	None		54	651	118	32	7.5	683	125.5	6.6	4.0	Fairly dark green; very few buds.
6	7	7	do	do		70	566	80	31.5	6	597.5	86	5.5	4.0	Lighter green than in 5.
7	21	7	do	do		75	939	151.5	52.5	11	991.5	162.5	7.5	4.8	Dark normal green; most vigorous plants in the test.
8	12	12	Jan. 24	Jan. 28	9	21	476	127	27.5	7.5	503.5	134.5	5	3.1	Dark normal green, darker green than in any other cabinet; very productive in yield of beans.

[1] Tests began Jan. 8, 1936, at germination, and were concluded Mar. 10; 12 plants in each pot, planted in a circle 2 inches from the periphery.

By referring to the equal ratios of light and darkness in table 4, showing alternations of 8 hours, 16 hours, and 12 hours in cycles of 16, 32, and the natural day of 24 hours respectively, it will be seen that only the plants receiving 12-hour intervals of light flowered.

The alternations of 8 and 16 hours, on either side of the 12-hour alternations, induced a purely vegetative expression, the taller plants being produced by the 8-hour alternation. With respect to dry material produced, there was little difference, and the foliage coloration exhibited about the same shade of greenness, which was lighter than in the 12-hour plants.

In cabinets 2, 3, and 4, receiving 8, 10⅔, and 13⅓ hours of light in relation to darkness in the ratios of 1:3, 1:2, and 1:1.4,

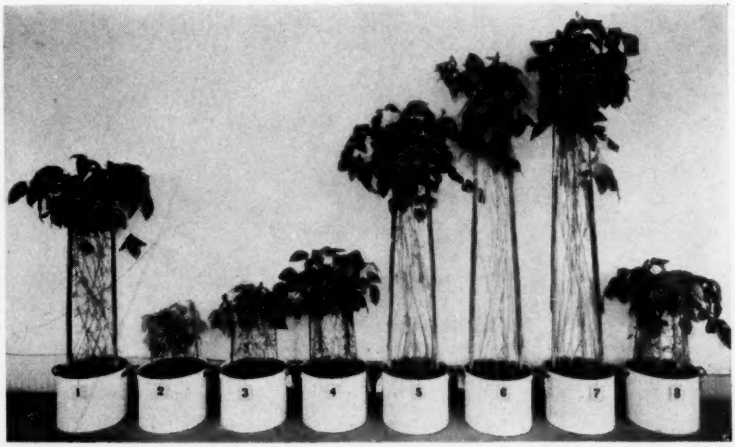

FIGURE 3.—Peking soybean (*Soja max*) grown under artificial light, with various ratios of light and darkness, in cycles of 14, 24, and 28 hours. Seed sown January 4, 1936; tests begun January 8, at germination. Plants photographed March 10, when tests ended. Numbers on pots correspond to designations of test cabinets.

1, 14 hours light; 14 hours dark. Buds February 8; flowered February 10 at 25 inches. Height when photographed, 50 inches.

2, 7 hours light; 21 hours dark. Buds January 28; flowered February 4 at 8 inches. Height when photographed, 14 inches.

3, 9⅓ hours light; 18⅔ hours dark. Buds January 28; flowered February 3 at 10 inches. Height when photographed, 16½ inches.

4, 11⅔ hours light; 16⅓ hours dark. Buds January 28; flowered February 3 at 11 inches. Height when photographed, 23 inches.

5, 16⅓ hours light; 11⅔ hours dark. Never budded. Height when photographed, 54 inches.

6, 7 hours light; 7 hours dark. Never budded. Height when photographed, 70 inches.

7, 21 hours light; 7 hours dark. Never budded. Height when photographed, 75 inches.

8, 12 hours light; 12 hours dark. Buds January 24; flowered January 28 at 9 inches. Height when photographed, 21 inches.

respectively, in the light-darkness cycle of 32 hours, all the plants flowered, but the flowering was delayed as the ratio of light to darkness increased or approached equality. This delay in flowering was accompanied by a consistent increase in height, in the amount of dry

TABLE 4.—*Flowering dates, heights, green and dry weights, and other data for Peking soybean grown in cycles of 16 and 32 hours* [1]

Cabinet No.	Light period	Dark period	Buds	First flowers	Height of plants at—		Weight of—						Mean dimensions of terminal leaflets of 5 leaves		Leaf color and other data at end of test
					Flowering	End of test	Tops		Roots		Total tops and roots				
							Green	Air-dry	Green	Air-dry	Green	Air-dry	Length	Width	
	Hours	*Hours*			*Inches*	*Inches*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Inches*	*Inches*	
1	16	16	None	None		45	594	68.5	27	5	621	73.5	6.8	4.3	About as dark green as in 6 and 7.
2	8	24	Apr. 20	Apr. 23	9	14	137	17	12	1.5	149	18.5	3.3	1.9	Very light green, lightest green in the series.
3	10¾	21¼	do	Apr. 27	17	28	263	31.5	16	2	279	33.5	4.7	2.6	Slightly darker green than in 2.
4	13¼	18¾	May 2	May 8	36	40	462	55	27	4.5	489	59.5	5	2.9	Slightly darker green than in 3.
5	18¾	13¼	[2]												Test failed.
6	8	8	None	None		56	556	72	31	5	587	77	5.2	3.4	Dark green; plants vigorous.
7	24	8	do	do		56	840	111.5	68.2	13	908.2	124.5	7.6	4.8	About as dark green as in 6; plants vigorous.
8 (check)	12	12	Apr. 9	Apr. 13	16	28	471	95	36	8	507	103	6.7	3.8	Darkest green in the series; productive

[1] Tests began Mar. 24, 1936, at germination, and ended May 11; 12 plants in each pot, planted in a circle 2 inches from the periphery.
[2] Plant died.

material produced, and in the size of the leaflets. There was naturally an increase in the greenness of the foliage with increase in the amount of light. Plants in cabinet 2, receiving only 8 hours of light in the cycle of 32 hours, were the palest green and the most etiolated in the series. Such behavior is normal, since in the natural cycle of 24 hours this corresponds to only 6 hours of light each day, an interval of illumination that fails to give vigorous plants.

With 13⅓ hours of light and 18⅔ hours of darkness, the ratio being 1:1.4, corresponding to a 10-hour day of the natural 24-hour cycle, flowering was considerably delayed. This delay in flowering suggests a trend toward purely vegetative expression, a trend which is

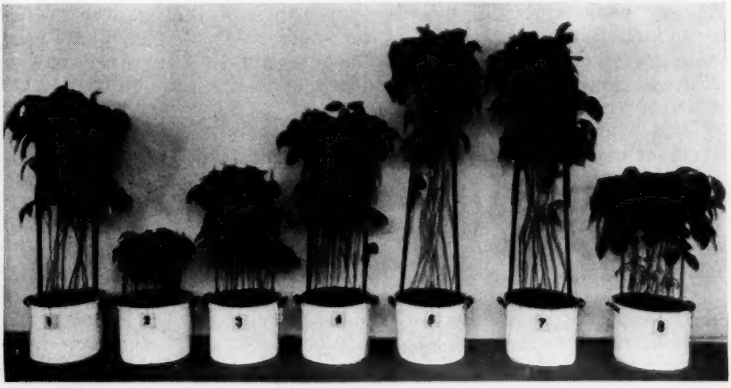

FIGURE 4.—Peking soybean (*Soja max*) grown under artificial light, with various ratios of light and darkness, in cycles of 16, 24, and 32 hours. Seed sown March 20, 1936; tests begun March 24, at germination. Plants photographed May 11, when tests ended. Numbers on pots correspond to designations of test cabinets.

1, 16 hours light; 16 hours dark. Never budded. Height when photographed, 45 inches.

2, 8 hours light; 24 hours dark. Buds April 20; flowered April 23 at 9 inches.

3, 10⅔ hours light; 21⅓ hours dark. Buds April 20; flowered April 27 at 17 inches.

4, 13⅓ hours light; 18⅔ hours dark. Buds May 2; flowered May 8 at 36 inches.

6, 8 hours light; 8 hours dark. Never budded. Height when photographed, 56 inches.

7, 24 hours light; 8 hours dark. Never budded. Height when photographed, 56 inches.

8, 12 hours light; 12 hours dark. Buds April 9; flowered April 13 at 16 inches.

further indicated by the great increase in height and amount of dry material produced.

There was no flowering in cabinet 7, where the light interval exceeded that of darkness in the ratio of 3:1, namely, 24 hours of light to 8 hours of darkness. This corresponds to an 18-hour day in the natural 24-hour cycle. With this increase in light, the largest yield of dry matter in the series was produced and the foliage developed a dark-green color.

As in all the previous tests with the Peking soybean, increase in the hours of light resulted in increased dry weight for the cycle of 32 hours.

Time of flowering was modified more by the ratio of light to darkness than by the length of the cycle itself (fig. 4).

HARD FEDERATION SPRING WHEAT

Table 5 shows the responses of the Hard Federation variety of spring wheat to the various light periods in cycles of 16 and 32 hours, as compared with the natural cycle of 24 hours. Referring to the equal alternations of 16, 8, and 12 hours of light and darkness in cabinets 1, 6, and 8, respectively, it will be seen that, although flowering was induced in all, the 8-hour alternations in the 16-hour cycle induced earliest flowering. Dry weights of the plants were not obtained, but the green weights were very different, the 16-hour alternations of the 32-hour cycle and the 12-hour alternations of the natural 24-hour cycle producing approximately the same green weight of material, both greatly in excess of that produced under the 8-hour alternations of the 16-hour cycle. These are differences of genuine significance, the cause of which is not as yet understood.

It is interesting to note that only two conditions in the 32-hour cycle failed to induce flowering in this wheat, namely, 8 hours of light and 24 hours of darkness, corresponding to a very short day of 6 hours of light in the natural 24-hour cycle, and 10⅔ hours of light and 21⅓ hours of darkness, corresponding to 8 hours of light and 16 hours of darkness in the 24-hour cycle, also a relatively short day in this natural cycle.

Where the ratio was increased to 13⅓ hours of light and 18⅔ hours of darkness, corresponding to 10 hours of daylight in the natural cycle of 24 hours, flowering was induced in one plant only, which produced a single head. This, then, may also be regarded as a short day unfavorable to flowering.

Flowering was induced readily when the period of light exceeded the period of darkness in a 32-hour cycle, as in cabinet 5, which received 18⅔ hours of light and 13⅓ hours of darkness, corresponding to a 14-hour day in the natural cycle of 24 hours, and in cabinet 7, which received 24 hours of light and 8 hours of darkness, corresponding to an 18-hour day in the natural 24-hour cycle. The green weight of plants was much greater in cabinet 5 than in cabinet 7, however.

A very striking feature of the behavior of the plants in cabinet 7, with the light-darkness ratio 3 : 1, corresponding to a high-latitude length of day in the natural 24-hour cycle, was the very early flowering, rapid growth, and quick maturity of the plants (fig. 5).

TABLE 5.—*Dates of heading and anthesis, green weight, and related data for spring wheat, Hard Federation variety, grown in cycles of 16 and 32 hours* [1]

Cabinet No.	Light period	Dark period	Heading	Pollen	Height of plants when pollen appeared	Tallest plant	Mean height of stems with heads	Tips of florets browning	Green weight of stems and roots	Average stems per plant	Average heads per plant	Average length of heads	Leaf color and other data at end of test
	Hours	*Hours*			*Inches*	*Inches*	*Inches*		*Grams*	*Number*	*Number*	*Inches*	
1	16	16	Feb. 5	Feb. 9	40	46.5	40.6	Feb. 17	713	9	5.8	4	Very dark green, vigorous.
2	8	24	None	None		20	19.8		108	7.2	None		Lightest green in the series.
3	10⅔	21⅓	do	do		26	23.9		317.5	10	do		Darker green than in 2.
4	13⅓	18⅔	Feb. 23	Feb. 25	34	40	34		639	9.7	(2)		Dark green.
5	18⅔	13⅓	Jan. 25	Jan. 29	43	48	42		478	6.6	5	4	Do.
6	8	8	do	Jan. 27	34	43	37.1	Feb. 15	433	6.2	5.7	4	Do.
7	24	8	Jan. 8	Jan. 13	34	41	33.8	Jan. 28	213	6.8	5.1	3.5	All dry, mature, with yellow straw, when harvested Feb. 25.
8 (check)	12	12	Feb. 1	Feb. 3	36	48	43.6	Feb. 23	697	7	5.3		Dark green.

[1] Tests began Dec. 14, 1936, at germination and ended Feb. 25, 1937; about 16 plants equally spaced in each pot.
[2] 1 plant with 1 head.

RUDBECKIA BICOLOR

With respect to the data presented in table 6, it may be stated that *Rudbeckia bicolor* was selected as a long-day type of plant. While it is true that this species flowers more readily when afforded relatively long days in the natural cycle of 24 hours, the plants showed considerable variability in their behavior, perhaps owing to the fact that selection for this character has not been rigidly followed and the species genetically may be rather impure with respect to length-of-day responses. However, the results with this plant have been striking and very interesting. Although the plants of each cabinet received the same total duration of light for the experiment, the various alternations showed widely different effects, more especially with respect to char-

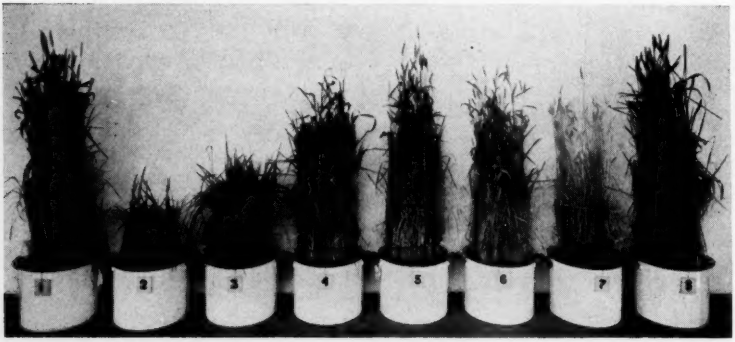

FIGURE 5.—Spring wheat (*Triticum aestivum*), Hard Federation variety, grown under artificial light, with various ratios of light and darkness, in cycles of 16, 24, and 32 hours. Seed sown December 8, 1936; tests begun December 14, at germination. Plants photographed February 24, 1937. Tests ended February 25. Numbers on pots correspond to designations of test cabinets.

1, 16 hours light; 16 hours dark. Heading February 5; pollen appearing February 9 at 40 inches.

2, 8 hours light; 24 hours dark. No heading when test ended.

3, 10⅔ hours light; 21⅓ hours dark. No heading when test ended.

4, 13⅓ hours light; 18⅔ hours dark. Heading February 23; pollen appearing February 25 at 34 inches.

5, 18⅔ hours light; 13⅓ hours dark. Heading January 25; pollen appearing January 29 at 43 inches.

6, 8 hours light; 8 hours dark. Heading January 25; pollen appearing January 27 at 34 inches.

7, 24 hours light; 8 hours dark. Heading January 8; pollen appearing January 13 at 34 inches.

8, 12 hours light; 12 hours dark. Heading February 1; pollen appearing February 3 at 36 inches.

acter of growth, stem elongation, floriferous tendencies, and size of heads.

The plants experiencing light and darkness in 12-hour alternations, a relatively short day for the natural 24-hour cycle, had produced very little stem growth with no flowers when the experiment was terminated. This behavior is normal for this plant, but there is reason to believe that flowering ultimately would have occurred, though after great delay.

TABLE 6.—*Data on flowering and growth of Rudbeckia bicolor plants grown under equal alternations of light and darkness, in 8 cycles ranging from 10 to 36 hours* [1]

Cabinet No.	Length of cycle	Light period	Dark period	Heading	First open flowers	Height at flowering	Notes on flowering and growth
	Hours	*Hours*	*Hours*			*Inches*	
1	10	5	5	Mar. 20	Apr. 6	26	Plants very floriferous; heads very large, the largest 3 inches in diameter. All plants produced stems and flowered; stems much more slender than in 2 and much less branched.
2	16	8	8	Mar. 23	Apr. 14	21	Plants very floriferous; flowers generally much larger than in 1, ranging from 3 to 4 inches in diameter; stems and leaves larger, coarser, and involucral bracts larger. All plants produced stems and flowered.
3	24	12	12	None	None	12	Very little stem development. Only 2 plants produced stems; the rest remained rosettes.
4	26	13	13	Mar. 26	Apr. 28	14	Stocky plants, only 2 flowering; largest head 3.75 inches in diameter. All plants produced stems.
5	28	14	14	Apr. 8	May 3	14	Very vigorous growth; few flowers; largest head 3.75 inches in diameter. All plants produced stems.
6	30	15	15	Apr. 3	Apr. 30	12	Very stocky plants, but few heads; largest head 3.75 inches in diameter. 3 plants produced stems, the rest remaining rosettes.
7	32	16	16	Apr. 8	May 3	18	Very vigorous, leafy plants; sparse flowering. Largest head, 3 inches in diameter. Only 2 plants produced stems, the rest remaining rosettes.
8	36	18	18	Mar. 29	Apr. 27	17	Flowering sparse; largest head, 4 inches in diameter. 4 plants with stems, the rest remaining rosettes.

[1] Seed sown Jan. 8, 1937; germination Jan. 22; plants remained in warm greenhouse until tests began Mar. 2, being then only small rosettes; 8 plants in each pot, spaced 2 inches from the periphery. Experiment discontinued Apr. 30.

Plants receiving the 5-hour and the 8-hour alternations flowered most quickly and most uniformly, since all produced stems and heads. Both alternations produced very floriferous plants and very large heads. There was a striking difference in these two lots of plants, however, those receiving the 5-hour alternations producing much slenderer and less branched stems than those receiving the 8-hour alternations. The stems of the latter were much larger and bore bigger and coarser leaves. Larger flower heads were also produced, having exceptionally big, coarse involucral bracts. In the case of these two equal alternations involving cycles much shorter than the natural 24-hour cycle, it was evident that plants receiving the 8-hour alternation had much greater vegetative vigor as well as greater reproductive vigor than those receiving the 5-hour alternation.

Plants receiving equal alternations in excess of the 12-hour alternation in cabinet 3, namely 13-, 14-, 15-, 16-, and 18-hour alternations, showed a striking tendency toward delayed stem growth and floriferous expression, growing very stocky, developing a dark-green color, and producing few but large heads. Many of the plants showed no stem elongation or only slight elongation at the close of the experiment.

The most striking feature of this test was the fact that the growth behavior of the plants was greatly modified by certain alternations of light and darkness (fig. 6).

ZINNIA ANGUSTIFOLIA

Table 7 shows data on the behavior of *Zinnia angustifolia*, a typical indeterminate type of plant, in tests involving equal ratios of light and darkness of ½, 1, 2, 12, 24, 30, and 36 hours, respectively, and continuous illumination. The largest, darkest green, and earliest flowering plants were produced with continuous illumination, the plants flowering nearly 2 weeks earlier than where very short alternations of light and darkness (½ hour) were used (fig. 7).

There was a trend toward increase in dry material as the equal alternations were increased in length in cabinets 1 to 4, inclusive, involving ½-, 1-, 2- and 12-hour alternations, respectively, but the weights were far below that produced by continuous illumination.

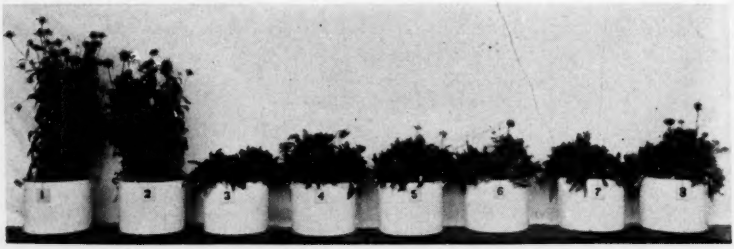

FIGURE 6.—*Rudbeckia bicolor* grown under artificial light, with equal ratios of light and darkness, in cycles of 10, 16, 24, 26, 28, 30, 32, and 36 hours. Seed sown January 8, 1937; germination January 22; tests begun March 2. Plants photographed April 30, when tests ended. Numbers on pots correspond to designations of test cabinets.

1, 5 hours light; 5 hours dark. Heading March 20; florets open April 6 at 26 inches.

2, 8 hours light; 8 hours dark. Heading March 23; florets open April 14 at 21 inches.

3, 12 hours light; 12 hours dark. No heading; stems just developing April 30, at end of test.

4, 13 hours light; 13 hours dark. Heading March 26; florets open April 28 at 14 inches.

5, 14 hours light; 14 hours dark. Heading April 8; florets open May 3 at 14 inches, after end of test.

6, 15 hours light; 15 hours dark. Heading April 3; florets open April 30 at 12 inches.

7, 16 hours light; 16 hours dark. Heading April 8; florets open May 3 at 18 inches, after end of test.

8, 18 hours light; 18 hours dark. Heading March 29; florets open April 27 at 17 inches.

With higher alternations, namely, 24, 30, and 36 hours, there was a tendency toward reduction in the dry matter produced. Alternations of 36 hours produced the smallest plants in the experiment, but with respect to greenness these were fairly dark, being scarcely lighter than the plants grown in cabinet 7 and very much darker than the light-green plants grown with ½-hour alternations (cabinet 1).

Strangely enough, plants receiving 24-hour alternations were nearly as yellowish green as the plants in cabinet 1, and the longer alternations (30 hours) produced much darker green plants.

The plants in cabinets 1a to 8a, inclusive, considering first the equal

alternations, showed a behavior similar to that of plants in the preceding experiment, those receiving ½-hour alternations of light and darkness having the lightest green foliage, with a gradual intensification of color as the light periods increased until continuous illumination was reached in cabinet 5a. The last-named test gave the darkest green plants in the experiment and the largest amount of dry material.

In cabinets 6a and 7a, receiving light and darkness in the ratio of 3:1, in cycles of 36 hours and 24 hours respectively, the time of flowering and greenness of foliage were approximately the same, but the dry matter produced was somewhat less in the case of the 36-hour cycle. With the light-darkness ratios reversed to 1:3, as in cabinet 8a, equivalent to a very short day, the plants were so badly etiolated that they were unable to flower (fig. 8).

The data presented in table 8 show the behavior of *Zinnia angustifolia* in response to equal alternations of light and darkness in cycles ranging from 10 to 36 hours.

The smallest yields of dry matter appear to have been produced with the longest alternations of light and darkness, namely, in cabinets

FIGURE 7.—*Zinnia angustifolia* grown under artificial light, with equal ratios of light and darkness, in cycles of 1, 2, 4, 24, 48, 60, and 72 hours and with continuous light. Seed sown January 10, 1939; germination January 13. Plants photographed March 1, when tests ended. Numbers on pots correspond to designations of test cabinets.

1, ½ hour light; ½ hour dark. Heading February 11; florets open February 23 at 17 inches.

2, 1 hour light; 1 hour dark. Heading February 9; florets open February 20 at 17 inches.

3, 2 hours light; 2 hours dark. Heading February 6; florets open February 20 at 17½ inches.

4, 12 hours light; 12 hours dark. Heading February 2; florets open February 13 at 13 inches.

5, Continuous light. Heading January 30; florets open February 9 at 10 inches.

6, 24 hours light; 24 hours dark. Heading February 10; florets open February 23 at 15 inches.

7, 30 hours light; 30 hours dark. Heading February 6; florets open February 25 at 16 inches.

8, 36 hours light; 36 hours dark. Heading February 11; florets open February 27 at 14 inches.

7 and 8, with alternations of 16 and 18 hours, respectively. Alternations of 5 hours of light and darkness in the short cycle of 10 hours produced but little more dry material. The intermediate cycles produced somewhat higher weights of dry material, but did not show particularly wide variations among themselves.

The dates of flowering in all instances were remarkably close (fig. 9).

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TABLE 7.—*Data on flowering, growth, green and dry weights, and related data for Zinnia angustifolia (Z. mexicana Hort.) in response to equal and unequal ratios of light and darkness* [1]

Cabinet No.	Length of cycle	Light period	Dark period	Heading	First open flowers	Height at flowering	Tallest plant at close of experiment	Weight of—						Leaf color and other data at end of test
								Tops		Roots		Total tops and roots		
								Green	Air-dry	Green	Air-dry	Green	Air-dry	
	Hours	*Hours*	*Hours*			*Inches*	*Inches*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	
1	1	½	½	Feb. 11	Feb. 23	17	22	196	5	19	1	215	6	Light yellowish green; lighter green than any other in this experiment. Plants slender with shorter branches.
2	2	1	1	Feb. 9	Feb. 20	17	27	326	11	34	1	360	12	Several shades darker green than in 1.
3	4	2	2	Feb. 6	do	17.5	26.5	400.5	10	40	1.5	440.5	11.5	About as dark green as in 2.
4	24	12	12	Feb. 2	Feb. 13	13	25	470	12	56	2	526	14	Do.
5	(2)	(2)	(2)	Jan. 30	Feb. 9	10	21	1,090	27.5	144.5	5	1,234.5	32.5	Darkest green plants in this experiment, with heaviest, stockiest growth.
6	48	24	24	Feb. 10	Feb. 23	15	15	322	10	29	1	351	11	Almost as light green as in 1.
7	60	30	30	Feb. 6	Feb. 25	16	16	300.5	10	27.5	1	328	11	Noticeably darker green than in 6.
8	72	36	36	Feb. 11	Feb. 27	14	14	186	5.5	17.5	.5	203.5	6	Not quite as dark green as in 7; smallest plants in experiment.
1a	1	½	½	Mar. 2	None		14.5	50	5.5	2.5	1	52.5	6.5	Very light green.
2a	2	1	1	Feb. 28	do		16.5	117	12	5	1	122	13	Somewhat darker green than in 1.
3a	4	2	2	Feb. 25	do		19	132	13.5	5	1.2	137	14.7	Somewhat darker green than in 2.
4a	24	12	12	Feb. 24	Mar. 7		18	233	22	7	1.5	240	23.5	Somewhat darker green than in 3.
5a	(2)	(2)	(2)	Feb. 21	Mar. 1		20	681	77	20	4.5	701	81.5	Darkest green of all the plants in this experiment.
6a	36	27	9	Feb. 23	Mar. 7		17	461	45	15.5	3	476.5	48.	About as dark green as in 4.
7a	24	18	6	do	Mar. 2		16.5	504.5	54	19	3.5	523.5	57.5	Do.
8a	24	6	18	None	None		6.5	2	.3	.5	.1	2.5	.4	Very pale green; plants badly etiolated.

[1] Experiments 1 to 8 inclusive began Jan. 10, 1938, and ended Mar. 1; experiments 1a to 8a inclusive began Feb. 4, 1938, and ended Mar. 9. 12 plants were grown in each cabinet.
[2] Plants in cabinets 5 and 5a received continuous illumination.

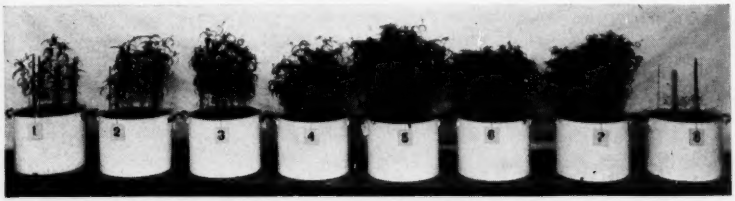

FIGURE 8.—*Zinnia angustifolia* grown under artificial light, with various ratios of light and darkness, in cycles of 1, 2, 4, 24, and 36 hours, and with continuous light. Seed sown February 1, 1938; tests begun February 4, at germination. Plants photographed March 9, when tests ended. Numbers on pots correspond to designations of test cabinets.

1, ½ hour light; ½ hour dark. Heads appearing March 2; florets never opened; height, 3½ inches when photographed.

2, 1 hour light; 1 hour dark Heads appearing February 28; florets never opened; height, 4 inches when photographed.

3, 2 hours light; 2 hours dark. Heads appearing February 25 at 4½ inches.

4, 12 hours light; 12 hours dark. Heads appearing February 24 at 5 inches.

5, continuous light. Heads appearing February 21 at 5 inches.

6, 27 hours light; 9 hours dark. Heads appearing February 23 at 5 inches.

7, 18 hours light; 6 hours dark. Heads appearing February 23 at 5 inches.

8, 6 hours light; 18 hours dark. Never headed; sickly, nearly died; height 3½ inches when photographed.

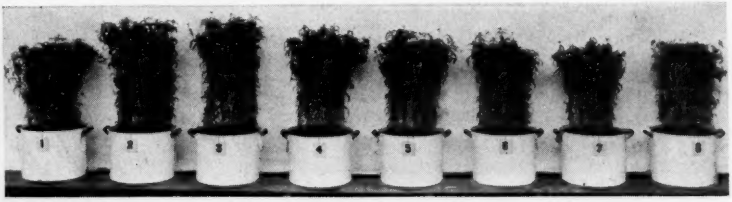

FIGURE 9.—*Zinnia angustifolia* grown under artificial light, with equal ratios of light and darkness, in cycles of 10, 16, 24, 26, 28, 30, 32, and 36 hours. Seed sown December 6, 1937; tests begun December 10, at germination. Plants photographed January 24, when tests ended. Numbers on pots correspond to designations of test cabinets.

1, 5 hours light; 5 hours dark. Heading December 31; florets open January 15 at 17 inches.

2, 8 hours light; 8 hours dark. Heading December 29; florets open January 13 at 17 inches.

3, 12 hours light; 12 hours dark. Heading December 29; florets open January 11 at 18 inches.

4, 13 hours light; 13 hours dark. Heading December 31; florets open January 14 at 17 inches.

5, 14 hours light; 14 hours dark. Heading December 31; florets open January 11 at 14½ inches.

6, 15 hours light; 15 hours dark. Heading December 29; florets open January 12 at 15 inches.

7, 16 hours light; 16 hours dark. Heading December 31; florets open January 13 at 16 inches.

8, 18 hours light; 18 hours dark. Heading December 31; florets open January 15 at 14 inches.

TABLE 8.—*Data on flowering, growth, green and dry weights, and related data for Zinnia angustifolia (Z. mexicana Hort.) in response to equal ratios of light and darkness in cycles ranging from 10 to 36 hours* [1]

Cabinet No.	Length of cycle	Light period	Dark period	Heading	First flowers	Height of plants at flowering	Weight of—						Leaf color and other data at end of test
							Tops		Roots		Total tops and roots		
							Green	Air-dry	Green	Air-dry	Green	Air-dry	
	Hours	*Hours*	*Hours*			*Inches*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	
1	10	5	5	Dec. 31	Jan. 15	17	483	53.5	11.5	2	494.5	55.5	Dark green, healthy.
2	16	8	8	Dec. 29	Jan. 13	17	719	71.5	15	2	734	73.5	About as dark green as in 1.
3	24	12	12	do	Jan. 11	18	507	57	10.5	2	517.5	59	Light green, slightly darker than in 8.
4	26	13	13	Dec. 31	Jan. 14	17	547	60	15	2	562	62	About as dark green as in 1.
5	28	14	14	do	Jan. 11	14.5	520	61.5	11.5	2	531.5	63.5	Slightly darker green than in 3.
6	30	15	15	Dec. 29	Jan. 12	15	516.5	64	12	2	528.5	66	Slightly darker green than in 8.
7	32	16	16	Dec. 31	Jan. 13	16	404	46	11	2	415	48	Slightly darker green than in 5.
8	36	18	18	do	Jan. 15	14	466	47.5	13.5	2	479.5	49.5	Very light green; lightest green in this series.

[1] Seed sown Dec. 6, 1937; tests began Dec. 10, at germination, and ended Jan. 24, 1938.

DILL

The data presented in table 9 show the behavior of dill, which is a plant of long-day habit, as is clearly indicated where the plants have been given a relatively short day of 12 hours in the natural cycle of 24 hours (cabinet 4). It will be seen that these plants were considerably delayed in time of flowering, and the character of growth was inclined toward a condition of vegetativeness with respect to total dry matter produced, density of foliage, and low-branching habit.

Continuous light appreciably hastened flowering, which was followed by rapid maturity. The plants were relatively slender but very productive of seed, indicating a condition favorable to high sexual expression rather than to purely vegetative growth.

The plants grown in cabinet 1, with ½-hour alternations of light and darkness, in the very short cycle of 1 hour, were among the poorest in the experiment with respect to yield of dry matter. They were the lightest green of all the plants in this test but were apparently vigorous.

When the equal alternations of light and darkness were increased to 1 hour and to 2 hours, there was an increase in dry matter produced, together with more or less increase in height and an intensified degree of greenness of the plants, but the dates of flowering were identical with that in cabinet 1.

With the longer light-and-darkness alternations of 24 and 30 hours (cabinets 6 and 7), in cycles of 48 and 60 hours respectively, the time of flowering was delayed but the amount of dry matter was increased, as was also the height of the plants. Both conditions produced rather slender, dark-green plants, but in the case of the 30-hour alternation there was a marked increase in height of plants and dry matter produced. These results indicate that conditions in both cabinets 6 and 7 tended to be favorable to vegetative expression rather than to sexual reproduction, the latter condition being favored very obviously by continuous illumination. In other words these plants were growing under conditions more comparable to those of plants receiving 12-hour alternations in the natural-day cycle of 24 hours than to those of plants receiving the short alternations of ½ hour, 1 hour, and 2 hours, in cabinets 1, 2, and 3.

Alternations of 36 hours of light and darkness (cabinet 8) were very distinctly unfavorable to the plants, although these finally developed a nearly normal green color. The striking feature of the effects of this alternation on the plants was the extremely sickly condition shown persistently for many weeks after germination, during which period the plants made almost no growth, remaining very yellow and etiolated, and a number finally dying. As time went on, a very gradual readjustment of the chlorophyll mechanism appeared to take place, with greening of the plants and renewal of growth until they were a fairly normal green at the conclusion of the experiment. Strong main stems, even at this time, were lacking, and the plants were very short. Only one plant had budded, and flowering probably would have taken place at some very much later date. The plants at the conclusion of the experiment appeared to be directed more to the vegetative than to the reproductive state (fig. 10).

TABLE 9.—*Data on flowering, growth, green and dry weights, and related data for dill (Anethum graveolens) in response to continuous light and various equal alternations of light and darkness* [1]

Cabinet No.	Length of cycle	Light period	Dark period	Buds	First flowers	Height of plants at flowering	Tallest plant at end of test	Weight of—						Leaf color and other data at end of test
								Tops		Roots		Total tops and roots		
								Green	Air-dry	Green	Air-dry	Green	Air-dry	
	Hours	*Hours*	*Hours*			*Inches*	*Inches*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	*Grams*	
1	1	½	½	Feb. 9	Feb. 17	18	26	95	18	2	2	97	20	Light green; plants vigorous.
2	2	1	1	do	do	23	30.5	117	23	3	2	120	25	Darker green than in 1; plants vigorous.
3	4	2	2	do	do	26	42	227	40	7	3	234	43	Darker green than in 2; plants very vigorous.
4	24	12	12	Mar. 4	Mar. 18	60	60	810	89	35	5	845	94	Deepest green of all tests; plants very stocky, very leafy, much branched, and branched very low; foliage dense.
5	(2)	(2)	(2)	Feb. 1	Feb. 8	25	46	285	84	7	4	292	88	Growth slender, rapid; rather sparsely leafy, but vigorous and early maturing; color a healthy green.
6	48	24	24	Feb. 23	Mar. 11	44	48	268	38	9	3	277	41	Dark green; plants rather slender.
7	60	30	30	Feb. 26	do	45	58	399	50	11	3	410	53	Dark green; as good leafage as in 6.
8	72	36	36	Mar. 19	None	5	28	141	14	9	3	150	17	Plants at first very weak, spindling, sickly; now showing a healthy green color; no central stems; would probably have flowered a week or 10 days later. Only 1 plant at this time has budded.

[1] Seed sown Jan. 5, 1940; experiment begun Jan. 10, at germination, 12 plants being grown in each pot, experiment ended Mar. 19.
[2] Plants in cabinet 5 received continuous illumination.

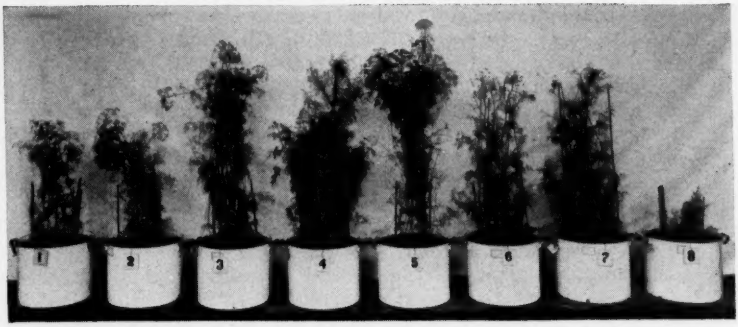

FIGURE 10.—Dill (*Anethum graveolens*) grown under artificial light, with equal ratios of light and darkness, in cycles of 1, 2, 4, 24, 48, 60, and 72 hours, and with continuous light. Seed sown January 5, 1940; tests begun January 10, at germination. Plants photographed March 6. Numbers on pots correspond to designations of test cabinets.

1, Light ½ hour; dark ½ hour. Buds February 9; first bloom February 17 at 18 inches.

2, Light 1 hour; dark 1 hour. Buds February 9; first bloom February 17 at 23 inches.

3, Light 2 hours; dark 2 hours. Buds February 9; first bloom February 17 at 26 inches.

4, Light 12 hours; dark 12 hours. Buds March 4; first bloom March 18 at 60 inches.

5, Continuous light. Buds February 1; first bloom February 8 at 25 inches.

6, Light 24 hours; dark 24 hours. Buds February 23; first bloom March 11 at 44 inches.

7, Light 30 hours; dark 30 hours. Buds February 26; first bloom March 11 at 45 inches.

8, Light 36 hours; dark 36 hours. Buds March 18; no flowering when tests ended March 19.

CONCLUSIONS

From an analysis of the preceding data it is obvious that the same ratios of light and darkness afforded in different cycles, as compared with the natural-day cycle of 24 hours, have given very different results in plant behavior, depending upon the species of plant, its length-of-day requirements, and the absolute length of the cycle itself.

In certain tests the production of dry matter, which is a measure of photosynthesis and growth, increased as the light interval increased. This is clearly shown with the Peking soybean, a short-day plant, where different ratios of light to darkness were employed in the same cycle, namely, the ratios 1:3, 1:2, 1:1.4, 1.4:1, 2:1, and 3:1, thus increasing the light interval. These increases in the length of the light interval gave an actual increase in the total light received during the course of the experiment, and with more total-functioning light there may well be more growth.

In the case of equal alternations of light and darkness, it is obvious that increase in the light interval does not increase the total amount of light received during the course of the experiment. However, certain tests have shown an increase in the dry matter produced as the light interval was increased in cycles involving equal alternations of light and darkness. This would indicate complex growth relations involving the light interval itself in relation to the dark interval,

since the total light and the total darkness are the same for the entire period of the test. In the case of *Zinnia angustifolia* the dry weight increased as the equal alternations increased up to 12 hours, as shown in the series involving alternations of ½, 1, 2, and 12 hours. With alternations of light intervals longer than 12 hours, however, i. e., in the series 24, 30, and 36 hours, there was a downward trend in weight of dry material produced with increase in the length of the light interval. These weights fall below those produced with alternations of 12 hours of light and darkness.

A similar behavior was shown by dill, a plant of long-day requirements, the dry weight increasing as the equal alternations increased up to 12 hours, in cycles of 1, 2, 4, and 24 hours. As in the case of *Zinnia angustifolia*, with alternations in excess of 12 hours, that is for 24, 30, and 36 hours, the weight of dry material again fell below that produced under the 12-hour alternation. The length of the cycle in this instance must somehow be concerned with growth as reflected in dry weights, in contrast to increases accompanying increased durations of light in a constant cycle.

On a purely photosynthetic basis there would be no reason to expect a longer interval of light in a series of equal alternations of light and darkness to produce a greater amount of dry material, other conditions being equal, for during the course of an experiment the summation of total light remains unchanged, yet the dry weight has changed as indicated. It would appear in these instances that a portion of the dark interval is also somehow regulative of or even inhibitory to growth and that beyond a certain length of interval this effect of the dark period dominates the situation, so that less dry matter is formed or accumulated after a certain alternation has been exceeded.

It is interesting to note that while *Zinnia angustifolia* produced by far the greatest amount of dry material with continuous illumination, this was not true of dill. The latter produced somewhat less dry matter with continuous illumination than with 12-hour alternations of light and darkness.

While it cannot at present be explained why the various ratios of light and darkness produce their characteristic effects with respect to flowering and growth of the plants, one is forced to the conclusion that the same ratios of light and darkness in different cycles may give a very different picture of plant behavior for each cycle and for each species, as to both growth and reproduction. It is apparent that not only the ratio itself is important but also the absolute cycle within which the ratio is operative for both functions. This is shown by the marked differences obtained with different cycles in time of flowering, yield of dry material, height of plants, branching, and other features of growth and specialization of the plant body.

It is unquestionably true also that the fundamental physiology of the mechanism of metabolism and growth is sometimes affected adversely soon after germination, and that this effect is followed sooner or later by more or less complete readjustment to the unusual conditions. This has more than once been shown by a marked etiolation and sickliness of the plants at the outset, on certain equal alternations, with a gradual recovery and a return to fairly normal growth and greenness as time went on and more leafage was produced.

It would appear that perhaps an increase in leaf area is one of the factors concerned in this striking recovery.

SUMMARY

A study has been made of the responses of some plants to various photoperiods under artificial light alternating with darkness in various ratios. Continuous illumination also was used. Light was furnished by water-jacketed and water-cooled 110-volt, 1,000-watt incandescent bulbs equipped with reflector. One bulb was used in each cabinet, the intensity at 1 foot from the plants being about 1,200 footcandles.

Temperatures were maintained at approximately 77° F., with a relative humidity of about 60 percent, in all tests. The pots rested on counterpoised balances, and distilled water was added to compensate for water loss each day.

The ratios of light to darkness used were 1:3, 1:2, 1:1.4, 1:1, 1.4:1, 2:1, and 3:1. The standard adopted for control was 12 hours of light alternating with 12 hours of darkness, a ratio of 1 : 1 in a cycle of 24 hours, which is the natural cycle in most latitudes of the earth. Cycles as short as 1 hour and as long as 72 hours were used.

The plants studied were Peking soybean (*Soja max* (L.) Piper), *Zinnia angustifolia* H. B. K., Hard Federation variety of spring wheat (*Triticum aestivum* L.), *Rudbeckia bicolor* Nutt., and dill (*Anethum graveolens* L.). On the basis of the natural 24-hour cycle, Peking soybean is usually regarded as a plant whose flowering is favored by short days; *Zinnia angustifolia* is obviously indeterminate, or day-neutral, in its flowering relations to length of day; spring wheat and *Rudbeckia bicolor* are favored by long days with respect to flowering; and dill is likewise a long-day type of plant.

The outstanding result of the experiments was that in most cases the same ratios of light and darkness did not give the same behavior for any particular plant.

In the case of Peking soybean, a short-day plant, a 1:1 ratio of light and darkness produced ready flowering with 12-hour alternations. With 7- and 8-hour alternations flowering was inhibited; with 9- and 14-hour alternations flowering was delayed; and with 16- and 18-hour alternations, flowering was again inhibited. Increase in the interval of light afforded the plants in any given cycle resulted in increased growth and yield of dry matter. The time of flowering was dependent upon both the ratio of light to darkness and the length of the cycle.

The results secured with *Zinnia angustifolia* and dill, subjected to equal alternations of light and darkness in cycles ranging from 1 to 72 hours, showed more or less obvious differences in flowering behavior and growth characteristics. In the case of the former, a strictly indeterminate plant, time of flowering was less affected; but the character of growth, the dry matter produced, and the greenness of the foliage were markedly different. Dill, a long-day plant, showed marked differences in time of flowering as well as in height, dry matter produced, branching habit, and shade of greenness.

In addition to equal ratios of light and darkness, unequal ratios were also studied, including 1:3, 1:2, 1:1.4, and the reverse of

these, in different cycles. All produced characteristic effects, depending upon the species of plant, its length-of-day requirements, and the absolute length of the cycle used.

The results of the work herein reported indicate that increase in growth and the production of dry matter may be associated with increase of the light interval in two contrasting conditions. In the one the dry matter increased where the total light received during the course of the experiment was also increased, as in the case of unequal ratios of light and darkness in the same cycle. In the other, the dry matter increased where equal ratios of light and darkness were maintained in cycles increasing in length, that is, where the total amount of light remained the same during the course of the experiment.

INHERITANCE OF SUSCEPTIBILITY TO INFECTION BY HELMINTHOSPORIUM MAYDIS RACE 1 IN MAIZE[1]

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INTRODUCTION

In an earlier paper[2] *Helminthosporium maydis* Nisik. and Mke. was reported as occurring on dent corn (*Zea mays* L.) in Indiana, Illinois, and Ohio. The fungus is known to attack suscepts at all stages of development. Two morphologically indistinguishable races of the species were recognized on the basis of host specialization, symptoms produced, and relative virulence. It was proposed that *H. maydis* race 1 include the parasite which thus far has been limited in its parasitism to the one inbred line *Pr*. All other inbred lines and hybrids, including single crosses involving *Pr*, observed in the field or tested in the greenhouse proved to be highly resistant to this race. This paper reports the results obtained in a study of the inheritance of susceptibility to the disease caused by *H. maydis* race 1.

MATERIALS AND METHODS

Plants of three single crosses involving *Pr*, namely, *Pr* × *Hy*, *Pr* × 38–11, and *Pr* × *Tr*, were grown in the field in 1939, and their ears were selfed or backcrossed with pollen of *Pr*, the susceptible parent, to obtain F_2 and backcrossed seed respectively. F_2 seed produced in the greenhouse the previous winter from F_1 plants of the same single crosses was planted in the field and self-pollinated to obtain F_3 seed.

Seed of F_2, backcrossed, and F_3 progenies was planted in flats in the greenhouse during the following winter. When the seedlings attained the 3- to 4-leaf stage they were sprayed on two successive occasions with a spore suspension of *Helminthosporium maydis* race 1. After each application of inoculum to the plants the flats were placed in moist chambers for 15 to 17 hours. Preliminary trials indicated that this length of time in a moist chamber was sufficient to initiate infection and did not cause water soaking and subsequent necrosis of the tissues such as frequently occurs when corn seedlings are held in a saturated atmosphere for an extended period. Seedlings of the susceptible inbred line and seedlings of the resistant single crosses were placed in each moist chamber to serve as controls.

Inoculum was prepared in the following manner. A single ear of *Pr* known to be infected with *Helminthosporium maydis* race 1 was

[1] Received for publication December 18, 1940. Cooperative investigations of the Division of Cereal Crops and Diseases, Bureau of Plant Industry, U. S. Department of Agriculture, and the Department of Botany, Purdue University Agricultural Experiment Station.

[2] ULLSTRUP, ARNOLD J. TWO PHYSIOLOGIC RACES OF HELMINTHOSPORIUM MAYDIS IN THE CORN BELT. Phytopathology 31: 508–521, illus. 1941.

used as a stock culture. Prior to inoculating a seedling population a few kernels were removed from this ear, surface-sterilized, and plated on acidified potato-dextrose agar. When sufficient growth of the fungus was visible on the plates, transfers were made to several

FIGURE 1.—*A*, Pair of leaves of a susceptible segregate showing typical symptoms; *B*, pair of leaves of a resistant segregate showing minute flecks where penetration has taken place, but progress of the parasite has been arrested.

fresh plates of potato-dextrose agar. When the growth had covered the agar surface the spores were washed off in water and the suspension was transferred to an atomizer and sprayed on the seedlings. The ear of *Pr* infected with the fungus was used as a stock culture

in preference to a culture maintained on agar in order to avoid the possibility of inadvertent selection of nonpathogenic variants that frequently arise in artificial culture. Inoculum prepared in this way has always given consistent results on segregating seedling populations.

Symptoms developed rapidly, and 7 days after the last inoculation the seedlings were classified according to their reaction. Resistance and susceptibility are clear-cut (fig. 1), and no difficulty was experienced in determining the class to which a seedling belonged.

RESULTS

The data on the F_2 seedling segregations of the three original crosses are shown in table 1. Out of a total of 1,766 seedlings tested, 1,325 were resistant and 441 were susceptible. The deviation from a theoretical 3:1 ratio is not significant. In table 2 the results of the test of seedlings of the backcrosses are given. A total of 1,746 seedlings showed a segregation of 882 resistant and 864 susceptible. The deviation from a 1:1 ratio is without significance. The segration of F_3 families is presented in table 3. In a total of 275 families tested, 74 were resistant, 141 were segregating, and 60 were susceptible. The deviation in this case from a 1:2:1 ratio is not statistically significant and is attributable to sampling error.

TABLE 1.—*Segregation of resistant and susceptible seedlings in the F_2 populations from 3 crosses involving the inbred line Pr*

[100 kernels planted of each F_2 progeny]

Parentage	Resistant	Susceptible	Deviation from a 3:1 ratio	Deviation / Standard deviation
(*Pr* × 38-11)-1	78	22	3.00	0.69
(*Pr* × 38-11)-2	81	19	6.00	1.38
(*Pr* × 38-11)-3	72	28	3.00	.69
(*Pr* × 38-11)-4	80	20	5.00	1.15
(*Pr* × 38-11)-5	77	21	3.50	.82
(*Pr* × 38-11)-6	69	30	5.25	1.22
Total	457	140	9.25	.87
(*Pr* × *Hy*)-1	69	25	1.50	.36
(*Pr* × *Hy*)-2	72	28	3.00	.69
(*Pr* × *Hy*)-3	71	28	3.25	.75
(*Pr* × *Hy*)-4	74	24	.50	.12
(*Pr* × *Hy*)-5	73	27	2.00	.46
(*Pr* × *Hy*)-6	71	27	2.50	.58
Total	430	159	11.75	1.12
(*Pr* × *Tr*)-1	75	23	1.50	.35
(*Pr* × *Tr*)-2	76	20	4.00	.94
(*Pr* × *Tr*)-3	72	26	1.50	.35
(*Pr* × *Tr*)-4	75	20	3.75	.89
(*Pr* × *Tr*)-5	70	26	2.00	.47
(*Pr* × *Tr*)-6	70	27	2.75	.64
Total	438	142	3.00	.29
Grand total	1,325	441	.50	.03

The above results indicate that in the crosses studied resistance and susceptibility to *Helminthosporium maydis* race 1 are conditioned by a single pair of genes. It is suggested that these genes be designated as *Hm hm*. In heterozygous individuals resistance is completely dominant. The inbred line *Pr* is the only known source of the

recessive allelomorph for susceptibility. No crosses studied thus far indicate other than typical monogenic inheritance.

TABLE 2.—*Segregation of resistant and susceptible seedlings in the backcrossed progenies from 3 single crosses involving Pr*

[100 kernels planted from each backcrossed ear]

Parentage	Resistant	Susceptible	Deviation from a 1:1 ratio	Deviation / Standard deviation
(*Pr* × 38–11) × *Pr*–1	47	52	2.5	0.50
(*Pr* × 38–11) × *Pr*–2	47	52	2.5	.50
(*Pr* × 38–11) × *Pr*–3	51	49	1.0	.20
(*Pr* × 38–11) × *Pr*–4	52	46	3.0	.61
(*Pr* × 38–11) × *Pr*–5	44	55	5.5	1.01
(*Pr* × 38–11) × *Pr*–6	50	48	1.0	.20
Total	291	302	5.5	.45
(*Pr* × *Hy*) × *Pr*–1	49	45	2.0	.41
(*Pr* × *Hy*) × *Pr*–2	49	50	.5	.10
(*Pr* × *Hy*) × *Pr*–3	54	41	6.5	1.33
(*Pr* × *Hy*) × *Pr*–4	46	51	2.5	.51
(*Pr* × *Hy*) × *Pr*–5	50	50	.0	.00
(*Pr* × *Hy*) × *Pr*–6	42	47	2.5	.53
Total	290	284	3.0	.25
(*Pr* × *Tr*) × *Pr*–1	50	45	2.5	.51
(*Pr* × *Tr*) × *Pr*–2	50	44	3.0	.64
(*Pr* × *Tr*) × *Pr*–3	45	50	2.5	.51
(*Pr* × *Tr*) × *Pr*–4	54	45	4.5	.90
(*Pr* × *Tr*) × *Pr*–5	50	47	1.5	.30
(*Pr* × *Tr*) × *Pr*–6	52	47	2.5	.50
Total	301	278	11.5	.95
Grand total	882	864	9.0	.43

TABLE 3.—*Segregation of F_3 families*

[25 kernels planted of each family]

Parental cross	Number of F_3 families tested	Observed segregation of families			Theoretical segregation on 1:2:1 basis			χ^2	Range of *P*
		Homozygous resistant	Segregating	Homozygous susceptible	Homozygous resistant	Segregating	Homozygous susceptible		
(*Pr* × 38–11)	83	20	46	17	20.75	41.50	20.75	1.19	0.50–0.70
(*Pr* × *Tr*)	50	9	29	12	12.50	25.00	12.50	1.64	.30– .50
(*Pr* × *Tr*)	53	17	23	13	13.25	26.50	13.25	1.53	.30– .50
(*Pr* × *Hy*)	89	28	43	18	22.25	44.50	22.25	2.35	.30– .50
Total	275	74	141	60	68.75	137.50	68.75	1.60	.30– .50

SUMMARY

The dent corn inbred line *Pr* is unique in its susceptibility to infection by *Helminthosporium maydis* race 1. All other corn inbred lines and hybrids, including single crosses involving *Pr*, tested in the greenhouse or observed in the field proved to be highly resistant.

The susceptibility of the inbred line *Pr* to infection by *H. maydis* race 1 is inherited as a monogenic recessive. The pair of genes concerned have been designated as *Hm hm*.

EFFECT OF STAGE OF MATURITY AT TIME OF HARVEST ON GERMINATION OF SWEET CORN [1]

By C. W. CULPEPPER, *physiologist*, and H. H. MOON, *assistant pomologist, Division of Fruit and Vegetable Crops and Diseases, Bureau of Plant Industry, United States Department of Agriculture* [2]

INTRODUCTION

Several workers (*1*, *2*, *3*)[3] have shown that the quality of sweet corn as a table product is greatly influenced by its stage of maturity when harvested. The stage for optimum quality is generally considered to be that at which the grain has reached one-half to three-fourths of its full maturity as judged by its dry-matter content.

It has been shown by Straughn and Church (*7*) that there is little relationship between the sugar content of the grain at full maturity and the sugar content at the time when the table quality is maximum. It is thus obvious that it would be advantageous to make selections of desirable individual plants upon the basis of the characteristics of the grains at the edible stage rather than at full maturity. Such a procedure would be greatly facilitated if the ears could be harvested when in optimum condition for table use, a portion of each used for making the necessary tests for quality, and the remainder preserved for planting.

The question immediately arises as to how the premature harvesting of such material will affect its germinating power when subsequently used for seed. If the seeds germinate, will the subsequent growth and behavior of the plants be affected adversely? If so, to what extent? How immature can sweet corn be when harvested and yet possess ability to germinate and develop to maturity? How are viability and capacity for normal development related to composition and size of the developing grain? Are there differences in varieties? If so, how may these differences be explained? While several of these questions have been answered for field corn and some other grains, no extensive study of the behavior of sweet corn in particular has been made.

Certain varieties, such as Golden Bantam and Stowell Evergreen, appear to mature at different rates. Is there any relation between rate of maturity and viability of immature grains?

After the grain has reached its full development, what is the effect of delayed harvest on the viability under the field conditions that prevail in the warm, humid parts of the eastern United States?

Information bearing upon these questions will be of particular value to the geneticist and the plant breeder.

A number of workers have presented reports concerned with the effect of stage of maturity upon the germination of the seeds of several grain crops. Robinson (*5*), using two varieties of field corn, has made a rather comprehensive study of the physiological factors

[1] Received for publication February 3, 1941.
[2] The authors are indebted to D. N. Shoemaker, formerly of the Division of Fruit and Vegetable Crops and Diseases, for advice and suggestions in making the germination tests.
[3] Italic numbers in parentheses refer to Literature Cited, p. 359.

affecting germination. Sprague (*6*) has studied the effect of various factors on the dormancy, after-ripening, and germination of seed corn when harvested at different degrees of maturity. These writers have given a rather complete bibliography of the work done with corn and other grains, consequently no further review of the literature will be given here. Neither of these workers, however, dealt specifically with sweet corn; and it would be expected that, because of the wrinkled and tender character of the seed, sweet corn might behave differently from field corn and other grains.

MATERIAL AND METHODS

The sweet corn for the tests reported in this paper was grown at the Arlington Experiment Farm, Arlington, Va., on a sandy loam soil formed by dredging operations along the Potomac River. The plants generally made good growth and were characteristic of the respective varieties.

In two seasons the ears for the tests were tagged when the silks first appeared, and the samples for the tests were harvested at predetermined ages. The ears were pollinated naturally in two seasons, but in a third season the pollinations were made by hand in order to obtain an accurate record of the date of fertilization. Samples were generally taken at 1- or 2-day intervals from 5 to 25 days from date of silking. Beyond the 25-day stage the samples were taken at 5-day intervals.

The ears were harvested about 9:30 a. m. and the husks removed. A portion of the ears was dried with the grains on the cob, and from the remainder the grains were removed from the cob by cutting just below the base of the grain with a sharp knife. In some of the work the grains from one-half of each ear were removed from the cob and the remainder dried without so removing. The material for the germination tests was then dried in a constant-temperature room at 26° C. in a current of air from an electric fan. The length of time required to bring the seed to an air-dry condition (moisture content 10 to 12 percent) varied with the atmospheric humidity, the size of the grain, and the degree of maturity. Four to seven days were generally required to dry material cut from the cob, and 6 to 10 days to dry that on the cob. Varieties like Stowell Evergreen required longer than varieties like Golden Bantam. In some cases effort was made to vary the conditions so that ears of different sizes would dry in the same length of time. The humidity of the room was not measured, but the atmosphere was sufficiently dry to be unfavorable for the development of micro-organisms, and consequently the corn remained free from any signs of decay or fermentation during or subsequent to the drying process.

Immediately after cutting from the cob, samples of the material were taken for chemical analysis.

After being dried, the samples were stored until the following January, at which time the germination tests were made. Material for each germination test was obtained from a lot of 5 to 10 ears by shelling 2 rows of grains from opposite sides of each ear and combining the grains obtained. From this material, duplicate samples of 100 grains each were drawn, care being exercised to include grains from tip and base of the ears as well as from the middle region. These

duplicate samples were then planted in clean sand in the greenhouse. The time at which the plants appeared above ground was noted, and at the end of 2 weeks the plants were removed from the sand and the ungerminated seeds examined for presence or absence of decay.

In the first year the Golden Bantam and Stowell Evergreen varieties were used, both being planted on the same date. The Golden Bantam came into flower about 10 days earlier than the Stowell Evergreen, and there was a corresponding difference in the time of harvest. Harvesting of the Golden Bantam was continued at 1- to 5-day intervals until the series from both varieties was completed.

In the second year several plantings were made at such dates that flowering in the two varieties occurred at the same time. The harvesting of the samples for each age was done on the same date for the two varieties, to eliminate differences in the climatic conditions during the period while the ears were developing. In drying the material the Golden Bantam ears were placed at a somewhat greater distance from the electric fan than the Stowell Evergreen, so that the two varieties were brought to air-dry condition in about the same length of time.

RESULTS OF FIRST AND SECOND YEARS' TESTS

WEIGHT, DRY MATTER, SUGAR CONTENT, AND GERMINATION

The results of the first and second years' tests are given in table 1. The air-dry weight per grain of the young material is doubtless a little high, as a certain amount of chaffy material adhered to the base of the grains and could not be removed quickly without injuring the rather fragile pericarp. The very young material when quite dry was rather brittle and delicate, so that it was always necessary to handle it with considerable care. The dry-weight determinations of the older grains are much more exact.

It is to be noted that the percentage of germination between the 11- and the 15-day stages of maturity is very low and irregular in both years. After the 15-day stage the percentage of germination increased strikingly to the 20-day stage, at which time about 80 to 90 percent germinated.

The material cut from the cob at the time of harvest germinated less satisfactorily than that which was allowed to remain on the cob. This result may have been due in part to injury to the grain in cutting but was probably due for the most part to the fact that the grains remaining on the cob derive some sustenance from it during drying.

There is a good correlation between the percentage of dry matter in the grain at the time of harvest and the percentage of grains germinating. With dry matter below 18 percent for corn cut from the cob or 14 to 17 percent for that dried on the cob, germination was very poor; but with dry matter above 20 percent, germination was generally good whether the grains had been dried on or off the cob.

The power of germination does not seem to be directly related to the sugar content. The germination increased with age up to 22 to 25 days, but the sugar content increased to about the 16- or 18-day stage and then decreased. Thus, satisfactory germination was not obtained until the sugar content had declined considerably from its maximum.

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TABLE 1.—*Air-dry weight, dry-matter content, sugar content, and germination of seeds of the sweet corn varieties Golden Bantam and Stowell Evergreen, harvested at different stages of maturity, in first and second years' tests*

GOLDEN BANTAM

Age from date of silking (days)	Air-dry weight per seed				Dry matter at harvest		Sugar content at harvest		Germination of seeds in greenhouse			
	First year		Second year		First year	Second year	First year	Second year	First year		Second year	
	Dried on cob	Dried off cob	Dried on cob	Dried off cob					Dried on cob	Dried off cob	Dried on cob	Dried off cob
	Gram	*Gram*	*Gram*	*Gram*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
8						9.41		3.57	0	0	0	0
9			0.0113						0	0	0	0
10	0.0181	0.0172	.0113	0.0108	10.42	8.87	3.62	3.04	0	0	4	0
11	.0312	.0291		.0122					0	0	2	0
12	.0356	.0311	.0290	.0221	12.69	11.62	4.71	4.53	1	0	25	0
13	.0471	.0420	.0265	.0292					6	0	6	1
14	.0636	.0662	.0425	.0296	14.89	12.14	6.03	6.12	6	2	55	0
15	.0697	.0668	.0533						10	6	65	0
16	.0894	.0714	.0564	.0484	18.36	14.48	6.55	5.94	88	4	76	25
17	.0904	.0861	.0677	.0545					90	23	75	12
18	.0992	.0921	.0848	.0625	20.94	19.10	5.10	4.97	96	44	82	19
19	.1181	.1099	.0940	.0840					97	39	91	45
20	.1275	.1298	.1008	.0855	23.24	21.64	4.12	4.12	94	46	77	78
22	.1353	.1314	.1248	.1053	27.41	25.16	4.00	3.90	99	85	97	96
25	.1511	.1581	.1459	.1288	33.96	30.13	3.61	2.47	98	87	100	99
30	.1812	.1841	.2022	.2044	40.85	36.64	1.85	1.54	99	87	98	100
35			.2369	.2212		42.32					99	100

STOWELL EVERGREEN

9						9.14		3.29	0	0	0	0
10	0.0118	0.0100	0.0140	0.0143	10.12	9.01	4.12	3.18	0	0	0	0
11	.0128	.0119	.0093	.0129					1	0	2	0
12	.0124	.0125	.0101	.0156	11.46	10.64	4.36	4.59	4	2	0	0
13	.0168	.0154	.0133	.0135					20	1	4	0
14	.0187	.0185	.0291	.0226	13.77	12.32	4.92	4.32	40	4	24	2
15	.0236	.0200	.0320	.0243					25	20	61	0
16	.0287	.0246	.0398	.0345	17.16	14.72	6.51	5.87	74	16	55	5
17	.0374	.0381	.0432	.0400					79	49	66	20
18	.0528	.0506	.0531	.0514	19.02	17.21	5.39	5.76	90	55	74	26
19	.0702	.0691	.0664	.0648					97	80	72	42
20	.0804	.0812	.0804	.0773	21.30	19.27	4.29	4.52	98	80	88	59
22	.0864	.0834	.1043	.1054	26.14	22.64	3.87	3.85	99	88	88	94
25	.0955	.0901	.1301	.1184	27.44	24.82	3.45	3.02	98	93	99	95
30	.1634	.1602	.1971	.1740	32.18	29.77	2.65	2.86	100	91	100	100
35	.2150	.2190	.2041	.1822	36.71	36.32	1.50	1.71	100	98	97	98

It was expected that, since the Golden Bantam appeared to mature more rapidly than the Stowell Evergreen, it would also germinate at a somewhat earlier age. In the material cut from the cob there appeared to be no very significant difference between the varieties, but in the material allowed to dry on the cob the Stowell Evergreen germinated considerably better than the Golden Bantam the first year, whereas the opposite occurred the second year. There is no clear explanation for this reversal in behavior. The two varieties were not harvested at exactly the same dates. The differences may possibly have been due to differences in the growing conditions prevailing in the period between silking and harvest of the two varieties.

The material of Stowell Evergreen cut from the cob germinated somewhat better in the first year than in the second, but in Golden Bantam the differences were not consistent.

BEHAVIOR OF IMMATURE GRAINS WHEN PLANTED IN THE FIELD

The young plants germinated in the greenhouse in the above tests showed tremendous differences in size and vigor that are not revealed by the percentages of germination. The size of the foliage as it appeared above ground was generally smaller the earlier the material was harvested. The plants from the seed harvested very young had the appearance of rye or wheat, and the very youngest appeared even as diminutive as some small-seeded grass. This, of course, raised the question whether such material when planted in the field would survive and develop to maturity.

A quantity of seed of the second crop harvested at different stages of maturity and dried without cutting from the cob was planted in the field in the following June. It was planted much more thickly than is ordinarily done. The conditions in the field were very favorable for germination, and in all except the very immature lots thinning was necessary to permit normal development of the plants. None of the plants from the seed harvested below 15 days of age survived to make a normal growth. The plants from the immature seeds appeared to be somewhat slower in getting established than those from the normal grain, but when once established they apparently grew as fast as the plants from the mature seed. The plants from the seed harvested at 15 to 17 days of age came into flower 3 to 6 days later than the plants from the mature seed.

There was very little difference in the date of flowering of any plants from seed harvested at 20 days of age or more, although the weight of the seeds varied greatly between the 20- and 30-day stages. It appeared quite possible to grow a crop satisfactorily in the field from seeds harvested 20 days or more after pollination. Of course, the minimum safe age for harvesting seed would depend upon the climatic conditions prevailing during the development of the grains, the required age at time of harvest being greater for material developing during the cooler part of the growing season or in northern sections.

THIRD YEAR'S STUDIES

In the third year's work all pollinations were made by hand in an attempt to get more uniform results. It had been suspected that the irregular results of the first 2 years' germination tests were due in part to the younger age of the grains near the base and tip of the ear than those near the middle of the ear, which are naturally fertilized first. The ears were bagged a few days before the silks appeared, and 2 days after the silks first appeared the ears were pollinated with fresh pollen from the same variety as the ear that was being pollinated. The ears were kept bagged until harvested. The pollinations were made between 9 and 11 a. m., and the ears were harvested at the same period of the day at 2-day intervals beginning the day after pollination.

WEIGHT, DRY MATTER, SUGAR CONTENT, AND GERMINATION

In addition to testing grain dried with and without cutting from the cob, another series was taken by harvesting the entire aerial portion of the plant, bringing it into the laboratory, and allowing it to dry at ordinary room temperature until the outer husks became almost air-dry, after which the ears were removed from the stalks, the husks removed, and the drying completed in the constant-temperature room

under the electric fan. Twelve to eighteen days, depending on the age of the material, was required to complete the drying of the grains. The results of these tests are given in table 2.

The percentage of grains germinating was more consistent from day to day than in the previous years, but there still remained considerable irregularity that must be attributed to causes other than differences in the age of the grains from pollination.

Differences between varieties appear too small to be of any particular importance.

TABLE 2.—*Air-dry weight, dry matter, sugar content, and germination of seeds of the sweet corn varieties Golden Bantam and Stowell Evergreen, harvested at different stages of maturity, in third year's tests* [1]

GOLDEN BANTAM

Age from date of pollination (days)	Air-dry weight of grain			Dry matter at harvest	Sugar content at harvest	Germination		
	Ear dried on stalk	Ear removed from stalk but grains dried on cob	Grains dried after cutting from cob			Ear dried on stalk	Ear removed from stalk but grains dried on cob	Grains dried after cutting from cob
	Gram	*Gram*	*Gram*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
2						0	0	0
4				10.10	3.40	1	0	0
6				9.84	3.56	2	1	0
8	0.0422	0.0361	0.0284	10.72	4.50	10	0	0
10	.0497	.0405	.0217	12.30	4.65	20	12	0
12	.0701	.0572	.0458	14.58	5.32	70	49	2
14	.0785	.0764	.0642	16.87	6.43	90	52	42
16	.1045	.0894	.0872	20.25	5.59	96	98	50
18	.1237	.1079	.1040	23.28	4.34	100	100	87
20	.1504	.1398	.1326	29.17	3.51	97	100	87
25	.1842	.1662	.1672	36.49	2.12	98	100	100
30	.2146	.2095	.1996	44.22	1.49	99	100	100

STOWELL EVERGREEN

2						2	0	0
4				9.73	3.81	0	0	0
6	0.0336	0.0235	0.0167	9.16	3.64	4	0	0
8	.0314	.0229	.0248	10.43	3.72	3	0	0
10	.0378	.0296	.0187	12.06	4.53	30	5	0
12	.0532	.0419	.0290	13.91	5.12	69	39	0
14	.0867	.0735	.0402	16.39	6.24	79	47	40
16	.1015	.0910	.0498	19.47	4.97	98	90	81
18	.1342	.1234	.0841	22.12	4.00	100	98	85
20	.1674	.1548	.1116	24.76	3.24	100	100	91
25	.2317	.2023	.1718	31.73	1.99	100	100	100
30	.2642	.2696	.2401	37.41	1.37	100	99	100

[1] The pollinations were controlled as to time by bagging the ears and pollinating them by hand at a specific time.

As in the former seasons, the seeds cut from the cob did not germinate as well as those allowed to dry on the cob. When the ear was partly dried on the stalk some grains germinated even when the plant was harvested the second day after pollination. Only a few grains harvested at the early stages germinated, and the results were irregular. On early harvested ears most of the grains cease development, but a very few continue to develop as long as they can receive nutrients from the cob. Culpepper and Magoon (*4*) noted that the grains upon ears of mutilated plants differ greatly in their chemical composition. Some grains continued their development almost normally, while others

ceased to develop soon after the mutilating treatment cut off the food supply to the ear. This variation in the development of individual grains doubtless is responsible for at least some of the irregularities in the results. There were apparently differences in ears and a possible difference in strains, but it was obvious that at least many of the grains received a certain amount of nutrients from the cob after harvest.

In the third year of the work 11 additional varieties were employed in the germination studies. The methods were the same as for Stowell Evergreen and Golden Bantam, but as a consequence of differences in rate of development the harvesting of all the varieties at one particular age after pollination could not be made on the same day. They were harvested in August, there being not more than 5 days' difference in the dates on which material of a given age was harvested for the different varieties. The conditions were fairly uniform during the period and were characterized by high temperatures, which resulted in a rapid development of the grains, and consequently germination was obtained in most cases in very young material.

Germination was first obtained in the 7- to 8-day samples with the varieties Mammoth Late, Howling Mob, Money Maker, Country Gentleman, and Bantam Evergreen, and in 9- to 11-day samples of Sweet Orange, Stabler Early, Sunnybrook, Long Island Beauty, and Golden Sunrise. The earliest age of harvest of seed at which it will survive planting in the field was not determined. Seeds harvested 19 to 20 days after pollination approached 100 percent germinating power.

Apparently, only rarely can germination be expected of seeds from ears harvested less than 10 days after pollination, and such seedlings are so weak that they cannot develop into normal plants. As conditions are made more favorable for the survival of the embryo, the greater become the chances that it can develop into a normal plant.

The 3 years' results suggested that it would be possible to harvest sweet corn when it is 20 days of age from date of flowering, or at a time when it has maximum table quality, to make chemical analyses and other tests for the identification of desirable characteristics upon a portion of the ear and to dry the remainder and preserve it for subsequent planting. If the vigor of the plants from the immature seeds were not too much reduced, it would be feasible to make selections in this way with a knowledge of the particular qualities of each plant under consideration at the period of best table quality.

In cooperation with D. N. Shoemaker, the writers made more than 200 selections of self-pollinated ears of the varieties Golden Bantam and Stowell Evergreen. These were harvested 20 days after pollination, and half of each ear was used in making chemical analyses, tests for tenderness, and other tests, and the remainder was dried for planting the following year. The seeds of each of these immature ears were planted in the field and grown in the ordinary way without any special culture treatment. As would be expected, there was lowered vigor due to the effect of self-pollination, and this depressed further the decreased vitality resulting from the lessened reserves of food materials in the grain, thus making the young plants much less able to survive unfavorable conditions. In most cases, however, the seed from individual ears produced a crop of plants that was entirely satisfactory for the purpose of further selection. In many progenies the growth was practically as satisfactory as that obtained

with corn harvested at complete maturity, while in others very few plants survived to maturity. The Stowell Evergreen proved somewhat more satisfactory than the Golden Bantam.

EFFECT OF DELAYED HARVEST ON GERMINATION OF SEED

In the third and last year of the work, open-pollinated ears were harvested at 5-day intervals from 30 to 70 days from the date of the first appearance of the silks. The results of the germination tests upon these are given in table 3.

It is noted that beyond the 45-day stage the percentage of grains germinating decreased in both varieties. At 70 days from silking, only 57 percent of Golden Bantam and 52 percent of Stowell Evergreen germinated. This decrease in the percentage of germination was obviously due to the attacks of micro-organisms that found the ear a favorable place for growth.

Because of the very warm, often rainy and humid conditions prevailing in the middle of the summer in the Middle and South Atlantic States, the ears often do not dry out rapidly enough in the husk in the field to prevent decay. The corn-earworm often causes injury to the tip of the ear that may allow the entrance of rain water, and this, with the injury to the tissues, favors the development of the decay organisms. If seed is to be saved in this section of the country, it is generally necessary to dry the ears artificially.

From the results of these tests the most favorable time of harvest appears to be between the 35- and 45-day stages, or at a time when the grains have reached a dry-matter content of 35 to 50 percent. Excellent germination is obtained at 30 days of age, but the grains are generally so soft as to be easily injured by rough handling at this stage. It is ordinarily best to harvest the corn before the plant is entirely dead, but the ears should be practically mature. The plants usually have the appearance of field corn at about the time it is usually cut and shocked. Many of the leaves are beginning to turn brown and die, but the stalk and part of the leaves are more or less green.

TABLE 3.—*Effect of delayed harvest on the dry-matter content, the air-dry weight, and the germination of the sweet corn varieties Golden Bantam and Stowell Evergreen*

Age from date of pollination (days)	Golden Bantam			Stowell Evergreen		
	Dry matter	Air-dry weight per seed	Germination	Dry matter	Air-dry weight per seed	Germination
	Percent	*Gram*	*Percent*	*Percent*	*Gram*	*Percent*
30	44.22	0.209	98	37.41	0.269	100
35	45.14	.198	100	36.32	.234	99
40	56.93	.214	98	51.60	.256	98
45	53.40	.198	100	50.72	.244	96
50	62.81	.218	95	58.74	.264	97
55	69.14	.201	91	65.29	.239	85
60	65.40	.220	80	76.13	.271	76
65	74.10	.236	72	64.26	.242	66
70	70.80	.216	57	69.34	.231	52

SUMMARY

With material properly dried, an almost perfect germination of the grains of sweet corn was obtained with ears harvested long before the corn reached complete maturity. In the very early stages the power

of germination varied greatly with the age or maturity of the material, and there appeared to be no specific age or moisture content below which all the grains abruptly ceased to germinate. Below a certain age germination was progressively poorer the earlier harvesting was done. With ears harvested very early the grains germinated better when allowed to dry on the cob than when removed from the cob before drying. If the ear was allowed to remain on the cut stalk during the drying process, germination was still better. Apparently at least small quantities of nutrients are derived from the cob and stalk after harvest if the drying is not too rapid. It appears that on ears harvested very young and slowly brought to an air-dry condition certain grains develop much more fully than others and hence germinate while the others fail.

Results have been obtained indicating that the ears of sweet corn may be harvested at the proper stage of maturity for table use, tests made upon part of the ear for desirable table characteristics, and the remainder dried and preserved for subsequent planting. In this way selections of individual plants may be made at the time when the grains are at the proper edible stage rather than from the mature material. It was found possible to continue this treatment through three successive generations, thus giving an opportunity for the segregation of desirable characters not apparent in the mature grain.

When the ears of sweet corn are permitted to remain upon the stalk in the field in the vicinity of Washington, D. C., until fully air-dry, the grains may germinate very poorly, owing to the fact that microorganisms attack the material under the warm, humid conditions of this locality. For the production of good seed artificial drying is generally necessary. For this purpose the material should be harvested 35 to 45 days from date of flowering, or when the dry-matter content of the grain has reached 35 to 50 percent.

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THE CAUSES OF STILLBIRTH IN SWINE AND AN ATTEMPT TO CONTROL IT [1]

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INTRODUCTION

The death of young pigs just before or during birth is a common phenomenon, yet little attention has been paid to it. It is difficult to obtain reliable data on the extent to which it occurs, since information collected from breeders is usually incomplete. They do not bother, in many cases, to record all the dead pigs. Another source of error of the opposite sort is the listing of mummified embryos born with the litter. Most reports in the literature concerning still-born pigs are incidental to other work and usually it has been necessary for the writers to calculate the percentage incidence for comparison with their data. A summary of the data found is given in table 1. The normal mortality for the United States lies between 5 and 8 percent. The numbers shown in table 1 are fairly uniform except the percentage for New Zealand, which is high, and that for Slovakia, which is low.

King (*4*)[2] gives the natal mortality in rats of the Wistar Institute strain as 1.31 percent for 31,670 rats born. She believes that not more than 8 percent of still-born rats were not recorded, so that "it would appear that the normal birth mortality in the colony, under existing conditions of environment and of nutrition, was not greater than 2 percent." She summarized data on human births collected by the United States Children's Bureau in selected cities of the United States, and found 4.4 percent still-born in 5,456 births, a figure more comparable to the swine figures than is her percentage for rats. Probably mortality would be higher in rat colonies not so meticulously cared for as those of the Wistar Institute.

TABLE 1.—*The incidence of still-born pigs as reported by different authorities*

Authority	Pigs born	Dead at birth	Source of data and remarks
	Number	*Percent*	
Carmichael and Rice (*2*)	5,840	8.1	Ill. Agr. Expt. Sta. data; includes immature pigs.
McKenzie (*7*)	[1] 2,011	[1] 8.2	Mo. Agr. Expt. Sta. data.
Aubel, Hughes, and Lienhardt (*1*).	[1] 161	[1] 8.1	Kans. Agr. Expt. Sta. data. Sows fed basal ration.
Aubel, Hughes, and Lienhardt (*1*).	169	[1] 2.4	Kans. Agr. Expt. Sta. data. Sows fed basal ration and wheat-germ meal.
Lush, Hetzer, and Culberston (*6*).	3,639	[1] 5.8	Iowa Agr. Expt. Sta. data.
McPhee and Zeller (*9*)	8,991	[1] 5.5	Beltsville Research Center, U. S. Department of Agriculture data.
Křiženecký (*5*)	31,686	[1] 3.2	Controlled Pig-Raisers' data, Slovakia.
McMeekan (*8*)	4,190	9.6	Pig Recording Club, New Zealand.
Russell [2]	7,749	7.5	Data from 5 United States experiment stations.
This paper	1,882	6.6	Data from Cornell University herd, Ithaca, N Y.

[1] Calculated for this table.

[2] RUSSELL, E. Z. THE RELATION OF BIRTH WEIGHT TO GAINS OF PIGS. U. S. Bur. Anim. Indus., Anim. Husb. Div. Mim. Paper, 3 pp. 1933.

[1] Received for publication December 7, 1940.

[2] Italic numbers in parentheses refer to Literature Cited, p. 369.

The work of Aubel, Hughes, and Lienhardt (*1*) suggests that mortality might be greatly reduced by the addition of wheat-germ meal to the ration of the sow, but in view of the composition of the basal ration, it is difficult to see in what way this could have improved it. The most thorough investigation of the causes, or rather the relationships, of stillbirth in pigs, is that of McPhee and Zeller (*9*). They found that stillbirth was related to litter size, as the smallest (1 to 2) and the largest (15 and above) litters had the greatest mortality at birth. To explain this they suggest that the smaller litters suffer most because they may be but the surviving remnants of litters that were larger at conception. The greater incidence of stillbirth in the largest litters is put down to the heavy physiological demands on the mother. They list the following as probable factors which influence birth mortality:

1. Errors in prenatal development
2. Nutrition, age, and care of the mother
3. Pathology
4. Lethal factors
5. Inherited endocrine disturbances

This classification is good, though it is doubtful whether a distinction can be drawn between factors 4 and 5. The list might be improved by adding one new class, accidental death, and a second, delayed birth, which might be a subdivision of class 2.

In the work herein recorded the writers have attempted to contribute to the knowledge of stillbirth in pigs through the collection of accurate records over a number of years and by autopsy of still-born pigs. When it seemed evident that delayed birth is a very important factor, an attempt was made with apparent success to reduce the mortality by the injection of pituitrin after the birth of the first pig in each litter. But the significance of the results obtained by this method now seems to be somewhat doubtful.

EXPERIMENTAL METHODS

Records were kept from the spring of 1930 of all pigs born alive or dead in the Cornell University herd. Whenever possible the order of birth and the birth weights were also obtained. The dead pigs were preserved in jars containing 5 percent formalin until about 100 had been saved. Mummified embryos were not counted or saved.

The university herd consists of purebred Berkshires, Chester Whites, and Duroc-Jerseys, with a very few crossbreds. The feeding and management have been kept fairly constant since 1930, but naturally there have been seasonal changes as well as changes of herdsman. Matings are made to get two litters yearly from the sows, in early spring and early fall. At the beginning of the period under discussion, the proportion of aged pigs was high, but by 1935, the end of the collection period, it had become the custom to keep the sows for a much shorter time so that the proportion of first litter sows was greater.

INCIDENCE OF STILLBIRTHS

During the period under discussion, 1930 to 1935, inclusive, the total number of pigs born was 1,882, of which 125 were dead. This is 6.6 percent, a proportion that compares favorably with the other figures from the United States. There was little breed difference, but it is noticeable that the incidence of still-born pigs is in the order

of average litter size (table 2). This may be important as it is shown in Table 3 that litter size has an influence on the percentage of pigs born dead.

TABLE 2.—*Stillbirths in pigs as related to breed and average litter size*

Breed	Average litter size	Still-born pigs
	Number	*Percent*
Duroc-Jersey	10.6±.31	7.2
Berkshire	10.5±.30	6.7
Chester White	10.1±.25	6.0

The size of the litter seems to have had some effect on the percentage of stillbirths (table 3). The figures for small litters are too scanty to give reliable information, but it is evident that with very large litters the birth mortality tended to increase. This is in accord with the results of other workers. Carmichael and Rice (*2*) found that the trend was high with small and large litters. McPhee and Zeller (*9*) observed the same trend. However, the writers question their suggestion that the increased mortality in large litters is due to an increased physiological drain on the mother, for the evidence in this work indicates that the increased duration of the birth process is an important factor.

TABLE 3.—*Stillbirths in pigs as related to litter size*

Litter size	Litters	Dead pigs	Still-born pigs	Litter size	Litters	Dead pigs	Still-born pigs
	Number	*Number*	*Percent*		*Number*	*Number*	*Percent*
1 to 5	10	0	0	11	21	13	5.6
6	3	1	5.6	12	20	18	7.5
7	11	2	2.6	13	13	17	10.1
8	20	8	5.0	14	18	21	8.3
9	19	1	.6	15 to 20	16	31	12.2
10	26	8	3.1				

The age of the sow is another possible factor. The figures in table 4 show a definite trend toward an increase in birth mortality with the increase in the age of the sows. Kříženecký's (*5*) data show a similar trend from the first litter to the seventh, but afterwards there is a somewhat erratic decrease. Russell's [3] data show a fairly steady increase with age as definite as those of the present writers. McMeekan's (*8*) figures are more erratic but show the same trend.

TABLE 4.—*Stillbirths in pigs as related to age of the sow at time of delivery*

Age of sow	Litters	Still-born pigs
	Number	*Percent*
9 months to 1 year, 3 months	41	2.7
1 year, 3 months to 1 year, 9 months	38	5.2
1 year, 9 months to 2 years, 3 months	38	3.5
2 years, 3 months to 2 years, 9 months	23	9.6
2 years, 9 months to 3 years, 3 months	14	9.8
Above 3 years, 3 months	20	14.1

[3] RUSSELL, E. Z. AGE AS A FACTOR IN BROOD SOW PERFORMANCE. U. S. Bur. Anim. Indus., Anim. Husb. Div. Mim. Paper, 4 pp. [n. d.]

There seems to be a seasonal influence also, as the mortality in 92 litters farrowed in the spring was 9.2 percent and in 88 litters farrowed in the fall, 4.9 percent. McMeekan's (*8*) pigs farrowed over a much longer period than did those of the writers. Taking comparable periods, his fall farrowings were the higher, with 12.5 percent mortality, and his spring farrowings the lower, with 5.0 percent mortality. The winters in the Manawatu-Oroua district of New Zealand in which these pigs lived are very mild with rare frosts, and there is far less difference between seasons than at Ithaca, N. Y., where the writers' pigs are kept. Evidently, if the Ithaca and Manawatu-Oroua data are representative, the factors at work which influence the seasonal incidence are totally different in the two localities. King's (*4*) rat data give a higher incidence of stillbirths in the fall (3.04 percent) than in the spring (1.78 percent). These figures for rats are in accord with those from New Zealand for pigs. Perhaps the Ithaca results reflect the fact that the sows had several months of pasture feeding before the fall farrowing and only 1 month before the spring farrowing. Support for this view is gained from the fact that after the close of the work described in this paper, many sows were not given summer pasture and the incidence of stillbirths was high in the spring farrowing. Many of the dead pigs showed signs of thyroid (iodine) deficiency. Superficial edema, thickening of the fore limbs, and enlarged thryoids were observed. Ithaca is on the edge of the Great Lakes iodine-deficiency area.

The sex ratio of all the pigs born was 52.5 percent males, and that of the dead pigs 51.2 percent males. This may represent a very slight tendency for females to die more readily than males. Carmichael and Rice (*2*) found a sex ratio of 56 percent males in 402 still-born pigs. McPhee and Zeller (*9*) found that the sex ratio of dead pigs was 52.9 percent males (497 pigs) as compared with 52.2 percent males for all pigs. Evidently there is little or no tendency for mortality to be greater in one sex than in the other. King (*4*) however, found a very great excess of male stillbirths in her rats and also in her human data.

POSSIBLE CAUSES OF STILLBIRTH

There is no doubt that the tendency is for still-born pigs to be the more immature pigs in the litter, but this tendency is not complete, for dead pigs may be found in any weight class. The average weight of all pigs born was 2.6 ± 0.02 pounds, while that of the dead pigs was 2.1 ± 0.07 pounds, a difference of 0.5 pound. The coefficient of variation for all pigs born was 26; for pigs born dead it was 38. Lush, Hetzer, and Culbertson's (*6*) equivalent figures are 2.7 and 2.2 pounds, with approximate (calculated) coefficients of variation of 20 and 30 respectively. The weights of pigs born dead are, therefore, much more variable than those of all pigs born.

The still-born pigs saved were weighed, measured, and dissected. Weights were taken for the liver, stomach and intestines (empty), kidneys, lungs, brain, and heart. The averages with their constants are given in table 5. No similar figures for normal swine are available for comparison but the rank of the organs in degree of variability follows very closely that for normal newborn rats given by Jackson. (See table 5.) The variability in individual organs is naturally much greater, since there is far greater variability in body weight. The heart shows this more than any other organ.

TABLE 5.—*Average weights of organs in still-born pigs as compared with similar data for newborn rats*

Organ	Mean	Probable error	Standard deviation	Coefficient of variation	Jackson's (S) coefficient of variation [1] for newborn rats
Total weight	947 gm.	±23	358	38	[1] 12
Crown-rump length	29.2 cm.	±.3	4.4	15	
Brain	29.2 gm.	±.3	4.2	14	12
Heart	9.6 gm.	±.2	3.2	33	18
Kidneys	7.6 gm.	±.2	2.5	33	24
Liver	21.4 gm.	±.5	8.3	39	22
Lungs	22.3 gm.	±.6	9.1	41	23
Stomach and intestines (empty)	44.3 gm.	±1.2	19.0	43	[2] 38

[1] Approximate.
[2] With contents.

An attempt was made to decide for each of the 127 pigs dissected the probable cause of death. This could be no better than guesswork in many cases as it is difficult to decide to what extent extreme variation in the size of an organ is lethal. Where the difference in the weight of one organ was great as compared with the rest of the organs and with the body weight, the fact was noted and was given as the probable cause of death. Many of the pigs undoubtedly failed to live because of immaturity, but it is difficult to distinguish in all cases between smallness and immaturity of a lethal nature. It was decided arbitrarily that a pig smaller than 375 gm. would not be likely to live, but this is probably a very conservative estimate. There seems to be no reason to assume that excessive size would be lethal except as it affects the mechanics of birth.

When any organs were doubtful in appearance or showed gross lesions, they were sectioned and studied histologically. Paraffin embedding with haematoxylin and eosin staining was employed. Potassium ferrocyanide was used for the detection of iron in the liver and spleen.

The assigned reasons for failure of these pigs to live are as follows:

Immaturity and smallness	8
Disproportionate organ weights	18
Pathology	19
Endocrine disturbances and edema	19
Deformities of skeleton	5
Accidental death (e. g., birth injuries, crushing before herdsman saw pig)	13
No obvious reason for death	45
Total	127

The group designated "Disproportionate organ weights" may be subdivided as follows: Large heart, 5; large heart and kidneys, 2; large heart and brain, 1; large brain, 4; small brain, 5; small liver, 1.

It is difficult to decide what effect an enlarged heart would have upon the viability of the pig, but the hearts in these cases were extremely disproportionate as compared with the average. This is reflected, of course, in the high coefficient of variation already noted. Brain disproportion is probably a much more serious fault.

Under the heading "Pathology" two main types of lesion were noted: (1) White spots on the surface of the liver, caused by an extensive invasion of white blood cells (half of one large litter was

born dead, with these lesions in each pig), and (2) black spots on the spleen or on the spleen and liver, caused by heavy deposits of iron compounds. Other lesions listed were kidney and heart small, and necrotic calcified masses on left cornea; blood in thorax, lungs pitted and edematous, 2 cases; coagulated serous fluid in thorax, 2 cases; emphysema of lungs; liver atrophied, coagulated serous fluid in thorax.

It is realized that these descriptions are very incomplete and that the nature of the preservation of the pigs left much to be desired for this type of work. The descriptions are meant to indicate merely that pathology was present in these cases. Edema, when it occurred alone, was taken as indicative of thyroid deficiency and was classed under the heading of endocrine disturbances.

No swine abortion (*Brucella suis*) infection has been found in the herd during the course of this work.

The classification "Endocrine disturbances and edema" is somewhat vague. It was made because in a few cases edema was found to be associated with fairly obvious abnormalities in the size of the thyroid or thymus gland, but in most instances it was not so accompanied. Details and number of cases in this class are as follows:

Thymus large, edema, 2.
Thyroid large, edema, 2. In one of these the brain was small. There was very little hair. The right kidney was small and necrotic; the left kidney was hypertrophied so that the weight of the two together was close to the average for these organs.
Thymus large, neck rigid, 1.
Thymus large, 1.
Thyroid and spleen large, histology normal, 1.
General edema, 11.
Umbilical cord large and edematous, 1.

Skeletal and other deformities were few. They were as follows: Thickening of lower jaw, 2 cases (in one of these general edema was also present); hind legs drawn back, brain and alimentary canal small, 1; extreme hernia, 1; cleft palate, brain abnormally small, alae of nose not united, 1.

Accidental deaths were divided as follows: Fractured or compressed skull, 4; intracranial hemorrhage, 2; extensive bruises, 3; excessive hemorrhage from umbilical cord, 1; umbilical cord tight around body, 1; swallowed fetal membranes, 1; ruptured jugular vein, 1.

In all, about two-thirds of the deaths were provisionally accounted for, but it is obviously impossible to decide what proportion of these should be charged to heredity and what to disease processes. The small number of structural anomalies is surprising.

After a number of the pigs had been dissected, it was realized that there was considerable difference in the appearance of the lungs when they were sliced. Some had obviously been inflated, but many had not. The lungs of the last 105 pigs were sectioned and examined histologically. The results are striking: Alveoli collapsed, 35; alveoli partly open, 46; alveoli wide open, 24.

Many of the pigs die after they have breathed, many others are able partly to inflate their lungs, but die before they are able fully to inflate them. Others are dead before any attempt at inflation can be made. This led to the belief that many of the pigs were suffocated within the uterus or vagina. This conclusion was strengthened by the fact that stillbirth was known to occur more frequently when the farrowing was unduly prolonged. The question arose whether the

order of birth was also a factor. In several farrowings the exact order of birth had been recorded. These records showed definitely that the great majority of the still-born pigs were born late in the litter. Figure 1 illustrates this. The vertical line represents the division of litters into the first and second half farrowed. Still-born pigs are represented by an X. Twenty-six litters in all are charted. Nine pigs were born dead in the first half of the pigs farrowed, and 45 in the second half.

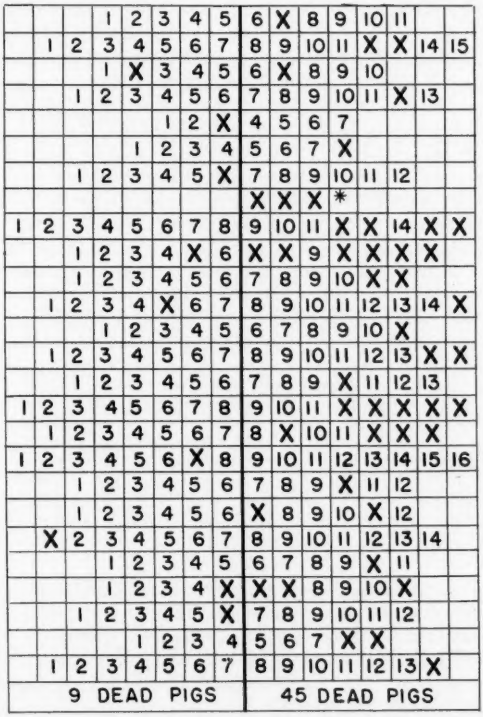

FIGURE 1.—Pigs still-born in the first and second half of the litters farrowed. The litters are recorded horizontally in the order of birth of the pigs with the dividing line at the center of the litter. Still-born pigs are indicated by X; asterisk (*) indicates 3 dead pigs born in the second half of a litter of 13.

AN ATTEMPT TO REDUCE THE INCIDENCE OF STILLBIRTHS

In the light of the foregoing results it seemed possible that mortality might be reduced by hastening birth. Accordingly, for the next five farrowing seasons—1936 to spring, 1938—2 cc. of pituitrin, U. S. P. IX at first and later 1 cc. of pituitrin U. S. P. XI, was injected into each sow immediately after the farrowing of the first pig or as soon thereafter as possible. The injection was made subcutaneously in the soft part of the neck, 2 or 3 inches behind the ear, the skin having first been swabbed with alcoholic iodine or alcoholic mercuric chloride

solution. During the period of the experiment 1,148 pigs were farrowed, and 33 of these were dead. This was a mortality of 2.9 percent. The average weight of the dead pigs was 2.1 pounds, the same as previously. These results seemed to justify the conclusion that the injection of pituitrin had markedly cut down the mortality, as there was a drop from 6.6 percent to 2.9 percent.

In order to establish a check on this result, during the next five farrowing seasons (fall, 1938 through 1940) insofar as possible alternate sows were injected. Of 352 pigs born to injected sows, 15 or 4.3 percent were still-born. Five of these pigs were born in one litter after a long delay in farrowing. Of 545 pigs born to sows that were not injected, 13 or 2.4 percent, were still-born. The difference in the number of pigs farrowed in the 2 groups is due not to a difference in litter size, but to the fact that more sows were left uninjected. Even if the 5 dead pigs in 1 litter were omitted, the injections would not have lowered the mortality below that in the noninjected sows. Furthermore, the current rate of mortality is exceptionally low, 2.9 percent, for all pigs during the 5 years of injections, a figure below that of any comparable series in the literature. No changes in management of the sows had been made that would appear to account for this decline. The writers are at a loss to explain it and they hope that others will repeat this work in order that further data may be obtained on the effects of pituitrin injections. The lower average age of sows in the second 5 years may account for some of the decline, but only for a small part.

SUMMARY AND CONCLUSIONS

The percentage of still-born pigs in the Cornell University herd over a period of 5 years was 6.6.

Large litters and advancing age of the sow tend to increase the birth mortality. Spring farrowings had nearly twice the mortality of fall farrowings. The mortality was no greater in one sex than in the other.

The average weight of still-born pigs was 2.1 pounds, as compared with 2.6 pounds for all pigs farrowed. The weight of still-born pigs was also more variable than that of all pigs farrowed.

As far as possible, the cause of death was ascertained. Disproportionate organ weights and pathological conditions seemed to be the principal contributory factors.

A considerable proportion of the pigs had made abortive attempts to breathe and had been smothered before birth. Most of the dead pigs were born late in the farrowing.

An attempt by the injection of pituitrin to hasten birth and thus reduce the mortality seemed to be successful at first, but subsequent work has thrown doubt on its value.

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COMPARATIVE INJURY BY THE EUROPEAN CORN BORER TO OPEN-POLLINATED AND HYBRID FIELD CORN [1]

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INTRODUCTION

Hybrid field corn (*Zea mays* L.) adapted to local conditions has been found superior to the common open-pollinated varieties of corn with respect to resistance or tolerance to some diseases and insects, the number of barren or earless plants, the degree of stalk breakage, and the yield of marketable grain. The possibility of its superiority with respect to tolerance to infestation by the European corn borer (*Pyrausta nubilalis* (Hbn.)) prompted the inclusion of several open-pollinated varieties among test plantings of hybrids in northwestern Ohio during the years 1929–33. The locally adapted Wooster strain of the open-pollinated Clarage variety was also grown by itself for comparison with the open-pollinated varieties as a group, not all of which were locally adapted. The determination of the comparative amount of injury to the quality and yield of the ears and also of breakage of the stalks was the primary purpose of this study.

A study of the injury to the quality of the ears should include, in addition to their marketability, the feeding value of the grain. This phase of the problem has been investigated by the Bureau of Animal Industry, United States Department of Agriculture, and the Chief of that Bureau made the following statement in his annual report for 1933: "Analyses of the separate parts of plants infested by corn borers show that the leaf, stalk, grain, cob, and husk were not markedly changed in composition. Reduced production in corn-borer-infested areas, therefore, can be measured chiefly on the basis of reduced yield." Accordingly, no additional data on grain analysis are presented in this paper.

STRAINS OF CORN USED

The group of open-pollinated varieties was made up, in 1930, of Red Cob Ensilage, Longfellow Flint, and the European varieties Telbisz Early Dent, Pferdezahn, and Bankuti Dent; in 1931, of Golden King, Krug, and Woodworth's Reconstituted High Yield and Reconstituted Reid; and in 1933, of Johnson County White, Smoky Dent, Clarage, Canterbury, and Doubet. There were 22 hybrids in the group tested in 1930, 15 of which were single crosses, 4 were three-way crosses, 2 were double crosses, and 1 was a top cross; of 20 hybrids tested in 1931, 18 were single crosses and 2 were double

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[2] The authors gratefully acknowledge material aid and advice received from J. R. Holbert, formerly of the Bureau of Plant Industry; J. S. Cutler and M. T. Meyers, formerly of the Ohio Agricultural Experiment Station; and the following workers in the Bureau of Entomology and Plant Quarantine, U. S. Department of Agriculture: W. H. Larrimer (now with the Forest Service), D. J. Caffrey, W. A. Baker, and Morris Schlosberg. The tests at Holgate, Ohio, during 1932 and 1933 were conducted on ground provided by the Ohio Agricultural Experiment Station.

crosses; and of 7 hybrids tested in 1933, 4 were single crosses, 2 were three-way crosses, and 1 was a double cross.

EFFECT OF BORER POPULATION ON THE QUALITY AND YIELD OF THE EARS

COLLECTION OF DATA AND STATISTICAL ANALYSES

The various strains of corn were subjected to different known levels of borer population. These strains were randomized within each of several replications. Each plot of a given strain was divided into as many equal subplots as there were levels of borer population in the experiment. One of the subplots was subjected to natural infestation only, whereas each of the others was, in addition, infested by hand with a definite number of egg masses per plant to produce the desired level of borer population. The eggs were produced in the laboratory.[3]

Some strains matured earlier than others, and the ears of these strains were a special attraction to blackbirds. Therefore, to avoid errors in comparing yields, all the ears were tightly covered with paper bags to protect them from the birds.

On an average 24 plants from each level of infestation of each strain were dissected after the middle of August to determine the mean number of borers per plant before many of the full-fed larvae had migrated away from the plants.

At harvest time record was made by subplots of the total number of productive plants, the number of earless plants, the number of plants bearing two ears, the number and weight of all the ears harvested, and the number and weight of the unmarketable ears. Plants maturing less than six kernels of grain were recorded as earless. Unmarketable ears were the chaffy, rotted, or moldy ears and nubbins so small that they would not ordinarily be harvested. Ears of sound grain, even though small, and ears with only a few of the kernels moldy were classified as marketable.

From the total number of plants in all the subplots of each level of infestation, the percentage that was earless and the percentage and the weight of ears that were marketable were calculated. These values were placed on an acre basis for a stand of 10,000 plants, thus permitting easy conversion of the numbers of plants per acre into percentages, and vice versa. The actual stands of 10 plantings of Clarage and 7 plantings of open-pollinated groups and of hybrids averaged 10,100 and 10,383 plants in 3,556 hills per acre, respectively. The yield was calculated in bushels of 56 pounds each of shelled corn on the basis of a moisture content of 15.5 percent.

The data from the 1930 planting of open-pollinated varieties, which averaged one borer per plant, are given as an example of the conversion of the data to an acre basis. On an average 5.5 percent of the plants, or 550 plants per acre, were earless. Therefore, 9,450 plants per acre were productive. Of the ears harvested, 93.0 percent were classified as marketable. On the assumption that each ear represented a productive plant, 8,789 plants per acre bore marketable ears and 661 plants per acre bore unmarketable ears. Of the ears harvested 98.6 percent by weight were classed as marketable. Since the estimated

[3] PATCH, L. H., and PEIRCE, L. L. LABORATORY PRODUCTION OF CLUSTERS OF EUROPEAN CORN BORER EGGS FOR USE IN HAND INFESTATION OF CORN. Jour. Econ. Ent. 26: 196-204, illus. 1933.

yield of the full stand of plants was 57.4 bushels per acre, the estimated marketable yield was 56.6 bushels per acre.

Finally, the simple regressions of the number of earless plants per acre, the number of plants bearing marketable ears, the total yield, and the marketable yield on the level of borer population were calculated Per-acre estimates were then made of the measurable quantities in the absence of borers, which in this paper are called the normal values. The results of the statistical analyses of all data are given in table 1.

As indicated in the example given above, one ear at harvest was assumed to represent one productive plant. Although the number of productive plants per plot was recorded, the identity of the individual ears from two-ear plants was lost when they were classified as marketable and unmarketable, and no record was obtained of the number of plants for each class of ears harvested. It was not possible, therefore, to determine the number of plants per acre bearing marketable ears. Two-ear plants, however, were few in number. During the period of the experiment the average percentage of two-ear plants of Clarage ranged from 0.4 to 2.4, with a general average of 0.9, and of the open-pollinated and hybrid groups from 0.5 to 4.6, with a general average of 2.1. The discrepancy introduced into the calculations by assuming an ear to represent one productive plant may therefore be considered as of no material importance.

The standard errors of the regression coefficients were calculated by Fisher's formula.[4] The variances of the different estimates in the absence of borers were calculated by a modification of the formula given by Ezekiel,[5]

$$e^2_{y'} = \sigma^2_{M_y} + (\sigma_{b_{yx}} M_x)^2$$

where $\sigma^2_{M_y}$ is the variance of the mean value of the factor of all borer levels, $\sigma_{b_{yx}}$ is the standard error of the regression coefficient, and M_x is the mean borer population of all levels.

The standard errors of the averages of all the plantings were calculated by the formula for the standard error of a general mean.

The number of degrees of freedom given in table 1 ranges from 1 to 4, indicating that the field data were obtained from three to six levels of borer population.

In estimating the effect of the infestation on the various factors, averages of all the plantings were used as a basis for comparison. Any differences between corresponding values of the Clarage and the open-pollinated groups may have been due to differences in variety, soil, planting date, or locality, but the values for the open-pollinated varieties and hybrids are directly comparable.

[4] FISHER, R. A. STATISTICAL METHODS FOR RESEARCH WORKERS. Ed. 6, 339 pp., illus. Edinburg and London. 1936. See section 26.

[5] EZEKIEL, MORDECAI. METHODS OF CORRELATION ANALYSIS. 427 pp., illus. New York and London. 1930. See p. 254.

TABLE 1.—*Per-acre estimates of the number and yield of plants bearing marketable ears, of the number of earless plants, and of the yield of the entire stand in the absence of borers, together with the expected increase, or decrease, per acre for each increase of one borer per plant for the tested types of corn, Ohio, 1929–33*

Date of planting	Locality	Per-acre estimates in absence of borer				Increase (+) or decrease (−) per acre for each increase of 1 borer per plant				Degrees of freedom
		Plants bearing marketable ears	Earless plants	Yield of plants bearing marketable ears	Yield of entire stand of plants	Plants bearing marketable ears	Earless plants	Yield of plants bearing marketable ears	Yield of entire stand of plants	
CLARAGE										
1929		*Number*	*Number*	*Bushels*	*Bushels*	*Number*	*Number*	*Bushels*	*Bushels*	*Number*
May 17	Toledo	6,722±238.7	325±230.2	38.2±1.11	49.8	−171±12.8	+73±13.8	−1.00±0.060	−1.00±0.039	4
1930										
May 7	Sandusky	8,287±230.4	663±159.9	52.7± .75	53.8	−183±57.2	+132±39.6	−2.63± .186	−2.52± .185	2
May 9	Huron	6,726± 90.8	1,999± 45.9	42.3± .76	43.5	−77±22.5	+82±11.3	−1.87± .189	−1.84± .141	2
1931										
May 6	Sandusky	8,793±180.8	517± 95.8	65.7±1.04	66.8	−120±15.6	+71± 8.3	−1.99± .090	−1.91± .084	3
May 7	Huron	6,546±186.0	2,210±161.1	41.6± .22	43.5	−193±22.1	+141±19.1	−2.02± .027	−1.96± .016	3
May 13	Toledo	8,247± 42.8	959± 29.1	51.5± .98	52.6	−123± 7.0	+58± 4.8	−1.79± .160	−1.67± .162	3
1932										
May 10	Toledo	8,324± 54.3	876±130.2	49.8± .82	50.8	−70± 7.7	+73±18.4	−1.45± .116	−1.45± .095	3
May 11	Maumee	8,297±305.1	711±238.9	43.7±1.52	45.5	−146±42.4	+92±33.3	−1.60± .210	−1.57± .221	3
	Holgate	7,863±275.5	931±108.1	54.5±2.89	56.8	−80±48.0	+88±18.9	−2.01± .503	−2.08± .470	3
May 17	Sandusky	9,290± 28.7	211± 43.6	84.0±1.42	84.9	−47± 4.5	+44± 6.7	−2.32± .218	−2.34± .218	3
Mean		7,910± 60.0	940± 45.2	52.4± .42	54.8	−121± 9.4	+85± 6.5	−1.87± .068	−1.83± .064	29
HYBRIDS										
1930										
May 8	Sandusky	9,690± 38.1	92± 37.2	73.9±0.26	74.3	−38± 9.4	+24± 9.2	−2.88±0.063	−2.88±0.063	1
1931										
May 5	do	9,306± 61.6	431± .6	86.6± .91	87.1	−16± 5.2	+2± .05	−1.63± .077	−1.58± .064	1
May 12	do	9,198±253.8	481±243.0	81.9± .06	82.7	−60±21.0	+37±20.1	−1.81± .005	−1.77± .048	1
May 19	do	9,076± 69.2	387± 64.4	77.9± .94	78.8	−99± 8.7	+71± 8.1	−2.39± .118	−2.34± .113	1
May 25	do	9,182± 87.2	458± 51.0	79.6± .62	80.2	−79±12.5	+40± 7.3	−2.57± .089	−2.48± .073	1

1933										
May 19	Toledo	9,898± 48.4	30± 18.5	96.4±4.92	98.5	−119± 5.5	+16± 2.1	−3.49± .558	−2.97± .553	1
June 2	do	9,578±124.1	23± 25.2	96.2±1.48	99.7	−16±23.2	+11± 4.7	−2.92± .277	−2.85± .533	1
Mean		9,418± 45.1	272± 37.3	84.6± .76	85.9	−61± 5.3	+29± 3.6	−2.53± .093	−2.41± .112	7

OPEN-POLLINATED GROUPS

1930										
May 8	Sandusky	8,981±340.2	430±302.3	60.9±0.62	61.7	−238±67.5	+162±60.0	−3.28±0.122	−3.23±0.093	1
1931										
May 5	do	8,319±403.9	1,001± 81.3	70.1± .93	71.2	−29±33.0	+8± 5.6	−1.40± .076	−1.31± .020	1
May 12	do	8,006±806.0	1,696±737.6	66.5±2.87	66.6	−113±76.7	+16±70.2	−2.14± .273	−1.84± .227	1
May 19	do	7,794± 56.0	966±508.2	55.4±5.32	56.7	−179± 6.9	+130±62.7	−1.97± .656	−1.73± .911	1
May 25	do	7,673±151.0	1,544± 71.0	55.9±4.54	56.9	−151±18.9	+45± 8.9	−1.96± .568	−1.69± .569	1
1933										
May 19	Toledo	9,026±133.9	71± 72.6	71.7±5.61	81.9	−169±13.2	+84± 6.6	−2.78± .553	−2.64± .228	1
June 2	do	9,230± 88.5	408±222.9	82.1±3.38	86.1	−161±13.5	+59±34.0	−3.61± .516	−3.18± .623	1
Mean		8,433±141.4	874±140.0	66.1±1.44	68.7	−149±15.8	+72±16.8	−2.45± .170	−2.23± .184	7

REDUCTION IN MARKETABLE YIELD

The comparative injury by the borer to the yield of the three groups of corn was studied from the standpoint of the reduction in marketable yield. Under infestations up to about five borers per plant there were no clear visual indications of reduction in yield, although broken stalks and signs of infestation were numerous. Under severe infestation the most noticeable indication of reduction in yield was the increase in the number of earless plants, but some infested plants bore only unmarketable nubbins or injured ears. From experimental evidence the ears of all infested plants appear to be more or less reduced in size, but in most fields, unless they are heavily infested, a general reduction in size would pass unnoticed. The borer reduces the marketable yield of corn plants, therefore, in three ways—(class 1) through an increase in the number of earless plants, (class 2) through an increase in the number of plants bearing unmarketable ears, and (class 3) through a reduction in the size of the ear on all plants bearing marketable ears.

To study the effect of these factors in reducing the marketable yield, it was desirable to put the loss in yield due to smaller ears on a plant basis for comparison with the other two factors. The yield obtained at a given level of infestation is usually compared with an estimated yield in the absence of borers. Hence the loss in yield due to smaller ears is expressed in terms of the number of plants that would produce an equivalent yield in the absence of borers. Expressing the loss in this manner is the same as regarding the loss that actually occurred on all the plants bearing marketable ears as being concentrated on a number of plants to the extent of rendering them earless. Since the yield harvested at a given level of infestation requires more plants than are required to produce this yield in the absence of borers, class 3 represents the excess plants that would be needed to compensate for the loss due to smaller ears.

The number of plants in class 3 was determined by first dividing the number of bushels of marketable corn per acre at a given infestation level by the normal yield in fractions of a bushel per plant bearing marketable corn to obtain the number of plants that should have produced an equivalent yield in the absence of borers, and then subtracting this number from the number of plants bearing marketable ears per acre at the given level of infestation.

The number of earless plants, the number of plants bearing marketable ears, and the number of bushels of marketable yield were calculated on a per-acre basis for a level of 12 borers per plant from the values in the absence of borers and the increase or decrease in these values per borer. The number of plants per acre bearing unmarketable ears was found by deducting the sum of the number of plants bearing marketable ears and the number of earless plants from 10,000. The number of plants in each of the three classes, in the absence of borers and at an infestation level of 12 borers per plant, is given in table 2. The difference between these two levels gives the increase in the number of plants necessary to compensate for the loss due to 12 borers per plant. The totals of the differences give the number of plants whose production in the absence of the borer would have equaled the total loss in marketable yield due to the borer.

TABLE 2.—*Classification of the loss to the various types of corn due to corn borer infestation at an average level of 12 borers per plant, Ohio, 1929–33*

Type of corn	Plants per acre			
	Earless plants (class 1)	Plants bearing unmarketable ears (class 2)	Additional plants required to compensate for loss due to smaller ears (class 3)	Total
CORN BORER ABSENT				
Clarage	940	1,150	0	2,090
Open-pollinated group	874	693	0	1,567
Hybrids	272	310	0	582
INFESTATION LEVEL 12 BORERS PER PLANT				
Clarage	1,960	1,582	1,930	5,472
Open-pollinated group	1,738	1,617	1,963	5,318
Hybrids	620	694	2,652	3,966
INCREASE NECESSARY TO COMPENSATE FOR BORER ATTACK				
Clarage	1,020	432	1,930	3,382
Open-pollinated group	864	924	1,963	3,751
Hybrids	348	384	2,652	3,384

From the number of plants in each class given in table 2, figure 1 was constructed to present the data graphically. A horizontal line was

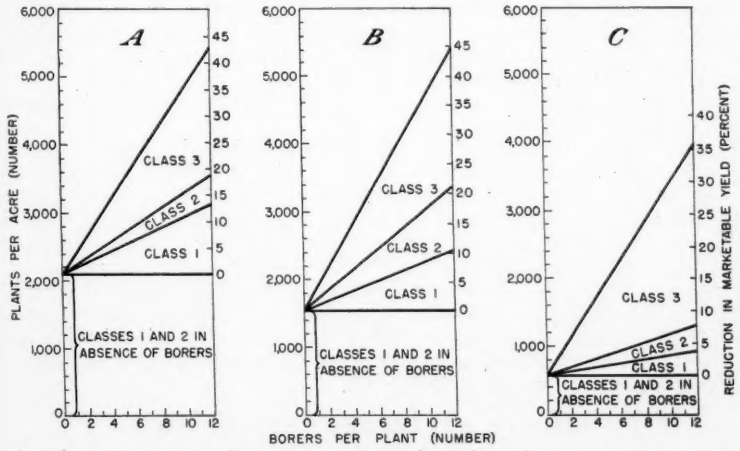

FIGURE 1.—Reduction in marketable yield of corn, classified according to character of injury resulting from corn borer attack at different levels of infestation: *A*, Clarage; *B*, open-pollinated group; *C*, hybrids.

first drawn at the level of the total number of earless and unmarketable ear-bearing plants in the absence of borers. Then the total increase in the number of plants necessary to compensate for borer attack at the 12-borer level was plotted above the horizontal line.

These points were connected with the origin at the no-borer level by a straight line. At the right of each figure a supplementary scale gives the percentage reduction in marketable yield due to the borer. This scale was erected on the basis of the total increase in number of plants necessary to compensate for the attack of 12 borers per plant as a percentage of the number of plants bearing marketable ears in the absence of borers. For example, the total increase of 3,382 plants in the Clarage strain is 42.76 percent of 7,910, the number of plants bearing marketable ears in the absence of borers.

The size of the ears was reduced about the same percentage in all three groups, because the ears on all the plants bearing marketable ears were smaller and the total reduction in marketable yield due to the corn borer was equivalent in each case to the yield from about the same number of plants in the absence of the borer. These results were obtained even though half the tests on Clarage were conducted during seasons in which the hybrids and the open-pollinated group were not tested and all but two of the tests on Clarage were conducted at different localities.

In the absence of borers 7,910 plants bearing marketable ears of Clarage yielded 52.4 bushels per acre (table 1), or 0.006624 bushel per plant. Owing to increases in the number of earless plants and plants bearing unmarketable ears, the number of plants bearing marketable ears was reduced 121 plants per acre per borer per plant, so that in the presence of 12 borers per plant 6,458 plants bore marketable ears. In the absence of borers, these 6,458 plants would have yielded 42.8 bushels of marketable grain. Since the marketable yield was reduced 1.87 bushels per acre per borer per plant (table 1), the yield was 30.0 bushels in the presence of 12 borers. Hence the yield was reduced 12.8 bushels and the size of the ears 29.9 percent owing to smaller ears on all the plants bearing marketable ears.

By similar calculation it may be shown that the size of the ears of the hybrids and the open-pollinated varieties was reduced 30.5 and 29.5 percent, respectively.

Since the marketable yields of Clarage, the hybrids, and the open-pollinated varieties were reduced, respectively, 1.87, 2.53, and 2.45 bushels per acre per borer per plant, an average of 12 borers per plant would reduce the yield 22.4, 30.4, and 29.4 bushels per acre, respectively. In the absence of borers a plant bearing a marketable ear averaged 0.006624, 0.008983, and 0.007838 bushel for the respective groups. Therefore, the total reduction in marketable yield due to 12 borers per plant was equivalent to the yield in the absence of borers of 3,382 plants of Clarage, 3,384 plants of the hybrids, and 3,751 plants of the open-pollinated varieties. These totals, calculated by another method, are given in table 2.

RELATIVE BORER DAMAGE TO DIFFERENT STRAINS

From the foregoing data it appears that the total reduction in marketable yield per acre per borer per plant was equivalent to the normal yield of an average of about 292 hybrid or open-pollinated plants, and that the size of the marketable ears of both the hybrids and the open-pollinated varieties was reduced on an average about 2.50 percent per borer per plant.

Although the total reduction in marketable yield due to 12 borers per plant was equivalent to the normal yield of about the same num-

ber of hybrid and open-pollinated plants, the loss of the hybrids was equivalent to the normal yield of 3,384 plants, which is 35.93 percent of 9,418, the number of plants bearing marketable ears in the absence of borers, whereas the losses of Clarage and the open-pollinated group were equivalent to 42.76 and 44.48 percent, respectively, of the normal yield. The loss for the hybrids was 2.99 percent per borer per plant as compared with 3.56 percent for Clarage and 3.71 percent for the open-pollinated group, or an average of 3.64 percent. Hence the hybrids were more tolerant to the borer than the open-pollinated varieties in that a given number of borers caused about five-sixths as much loss of yield to the former as to the latter. This advantage was due to the difference in the rate of increase in the number of earless plants and those bearing unmarketable ears per acre per borer per plant. For the hybrids the increases were 29 and 32 plants, respectively, as compared with 72 and 77 for the open-pollinated plants on the same plantings. In correlation with these lower rates of increase, the hybrids in the absence of borers would have had a smaller number of earless plants and plants bearing unmarketable ears and a correspondingly larger number of plants bearing marketable ears. The hybrids would have had 9,418 plants per acre bearing marketable ears in the absence of borers as compared with 7,910 plants of Clarage and 8,433 plants of the open-pollinated group. All these differences between the hybrids and the open-pollinated group are shown in figure 1.

The greater tolerance of the hybrids over the open-pollinated group may be shown as due to a given number of borers causing a smaller number of plants to become earless or to bear unmarketable ears, and not to a higher level of performance in the absence of borers. If the hybrids had lost the yield from as many plants bearing marketable ears as was lost by Clarage and the open-pollinated group, the loss would have been 14.6 bushels per acre from an average of 1,620 plants. The hybrids, then, would have had only 7,798 plants bearing marketable ears in the presence of 12 borers per plant. This number of plants would have yielded 70.0 bushels in the absence of borers. Since the size of the ears was reduced 30.5 percent by 12 borers per plant, the yield of 7,798 plants would have been reduced 21.4 bushels by the smaller ears on all plants bearing marketable ears. The total reduction in yield would have been 36.0 bushels, which is 42.6 percent of 84.6 bushels, the yield in the absence of borers, or 3.55 percent per borer per plant. This loss is about as much as was suffered by Clarage and the open-pollinated group, even though the hybrids would have had more plants bearing marketable ears in the absence of borers.

EFFECT OF BORER POPULATION ON BREAKAGE OF THE CORN PLANT

The effect of different levels of corn borer population on the breakage of corn plants through feeding and tunneling within the stalk was a study incidental to the determination of the reduction in the amount and quality of the yield. A thorough study of the comparative ability of different strains to stand up under given borer populations requires the taking of data at intervals during the harvest season, especially after heavy winds. This was not possible in the

present study, but it is believed that data from the Clarage variety taken from five localities during 4 years are fairly representative of an open-pollinated variety at harvest. It is believed also that sufficient data have been accumulated on open-pollinated varieties as a group and on hybrids to justify a comparison of the two groups.

COLLECTION AND CALCULATION OF DATA

Just before the harvest, during the last week of September and the first 2 weeks of October, the number of plants broken above the ear and the number broken below the ear were recorded for each plot. A plant broken both above and below the ear was recorded as broken below the ear. All breaks other than broken tassels were recorded, whatever the cause. The total number of plants per plot and the number of borers per plant at each infestation level were taken from the data used in the study of the quality and yield of the corn ears.

For the Clarage variety the number of plants broken below the ear was combined with the number broken above the ear to obtain the total number of broken plants, and the percentages of the plants broken were then calculated (table 3). Data from four levels of infestation from two plantings and five levels from nine plantings are given in table 3. Mean values are given for the plantings with five levels of infestation. For the groups of hybrids and of open-pollinated varieties complete data were obtained only on the number broken below the ear (table 4).

BREAKAGE OF CLARAGE AT VARIOUS INFESTATION LEVELS

For the Clarage variety it may be noted in table 3 that, as the number of borers per plant increased, both the total percentage of broken plants and the percentage of plants broken below the ear likewise increased. When the mean percentage of each variable was plotted against the average number of borers per plant for the five levels of infestation, a smooth curve could be passed through the points, as shown in figure 2. This curvilinear relation would necessarily follow from the way the data were taken. The number of broken plants, not the number of breaks per plant, was recorded. The ratio of the mean percentage of plants broken below the ear to the mean total percentage of broken plants, given in table 3, was about constant for the five levels of borer population, and averaged 59.0 percent.

COMPARISON OF BREAKAGE IN HYBRIDS AND OPEN-POLLINATED VARIETIES

The average breakage of hybrids is compared with that of open-pollinated varieties in table 4, and the curved lines in figure 3 are fitted to these data. It may be noted, by extending the curves to the left, that about 3.5 percent of the hybrid plants and 10.5 percent of the open-pollinated plants would have been broken in the absence of borers. The curves also show that about 14.5 and 20.0 percent of the plants, respectively, were broken at a level of seven borers. Seven borers per plant would therefore have caused the breakage of 11.0 percent of the hybrid plants and 9.5 percent of the open-pollinated plants. Since the difference of 1.5 percent is of no practical importance, seven borers would have caused the breakage of an average of 10.3 percent of the plants, or 1.47 percent per borer per plant. In the absence of borers about 7.0 percent more of the open-pollinated than

TABLE 3.—*Breakage of plants of Clarage corn at different levels of population of the European corn borer, northwestern Ohio, 1929–32*

Date of planting	Locality	First level			Second level			Third level			Fourth level			Fifth level		
		Borers per plant	Total plants broken	Plants broken below ear	Borers per plant	Total plants broken	Plants broken below ear	Borers per plant	Total plants broken	Plants broken below ear	Borers per plant	Total plants broken	Plants broken below ear	Borers per plant	Total plants broken	Plants broken below ear
1929		*Number*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*	*Number*	*Percent*	*Percent*
May 13	Sandusky	1.2	15.9	9.4	2.6	24.4	16.7	3.2	28.0	18.5	3.5	29.1	17.7	5.3	32.7	20.9
May 15	Huron	1.6	17.7	7.7	4.2	32.7	13.9	5.2	33.7	14.5	6.2	36.6	14.1	8.9	42.7	14.7
1930																
May 7	Sandusky	1.3	17.2	9.3	2.7	30.6	15.7	4.4	37.9	16.9	6.1	42.3	18.5			
May 9	Huron	1.1	13.1	5.0	2.6	20.6	9.3	4.7	33.2	13.0	5.8	36.4	14.1			
1931																
May 6	Sandusky	2.6	16.9	12.0	3.9	24.5	19.3	9.5	45.5	34.9	13.5	56.8	44.8	19.3	60.8	50.0
May 7	Huron	2.3	11.9	4.5	2.5	16.9	8.6	7.6	26.6	14.1	9.8	29.9	18.6	13.7	33.6	19.5
May 13	Toledo	.4	6.0	3.2	.9	13.3	8.9	5.2	30.9	14.2	7.8	38.8	20.9	8.9	43.6	24.5
1932																
May 11	Toledo	2.0	26.0	16.4	5.1	34.2	17.3	7.0	43.1	17.5	8.7	45.4	19.9	9.7	47.7	21.5
	Maumee	1.3	19.3	14.8	5.3	24.8	19.5	6.9	28.1	21.3	8.8	26.4	22.2	10.1	36.4	28.5
May 17	Sandusky	2.7	20.0	7.4	4.7	25.9	10.1	6.4	32.0	11.3	7.8	35.1	14.8	8.9	37.8	14.2
	Holgate	1.4	20.2	13.6	3.6	32.0	26.4	5.6	29.9	23.7	7.2	35.6	23.3	8.0	37.4	29.6
Mean (1929, 1931, and 1932)		1.7	17.1	9.9	3.6	25.4	15.6	6.3	33.1	18.9	8.1	37.1	21.8	10.4	41.4	24.8
Ratio of mean percentage of plants broken below ear to mean percentage of broken plants		57.9			61.4			57.1			58.8			59.9		

TABLE 4.—*Plants of hybrids and of open-pollinated varieties of corn broken below the ear at different levels of population of the European corn borer, Ohio, 1930–33*

Date of planting	Locality	Open-pollinated varieties						Hybrids					
		First level		Second level		Third level		First level		Second level		Third level	
		Borers per plant	Plants broken below ear	Borers per plant	Plants broken below ear	Borers per plant	Plants broken below ear	Borers per plant	Plants broken below ear	Borers per plant	Plants broken below ear	Borers per plant	Plants broken below ear
		Number	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*	*Number*	*Percent*
May 8, 1930	Sandusky	1.0	14.7	5.1	16.2	6.3	25.2	0.7	12.3	4.3	23.1	5.5	25.9
May 5, 12, 19, 25, 1931	do	2.9	12.3	8.9	19.5	13.9	18.0	2.4	6.9	8.8	12.7	14.2	15.2
May 20 and June 2, 1933	Maumee	.5	11.3	3.4	19.1	4.1	24.2	.4	2.4	2.5	6.3	3.5	11.0
	Holgate	.3	12.9	3.8	19.3	6.7	15.5	.2	1.9	2.9	4.9	4.1	5.3
Mean		1.2	12.8	5.3	18.5	7.8	20.7	.9	5.9	4.6	11.8	6.8	14.4

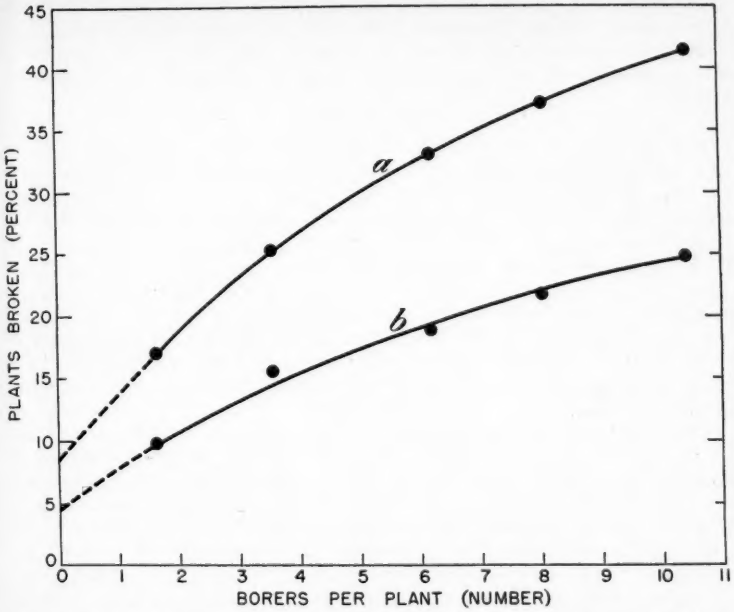

FIGURE 2.—Total percentage of broken plants (*a*) and percentage of plants broken below the ear (*b*) at different levels of borer infestation in the Clarage variety of corn.

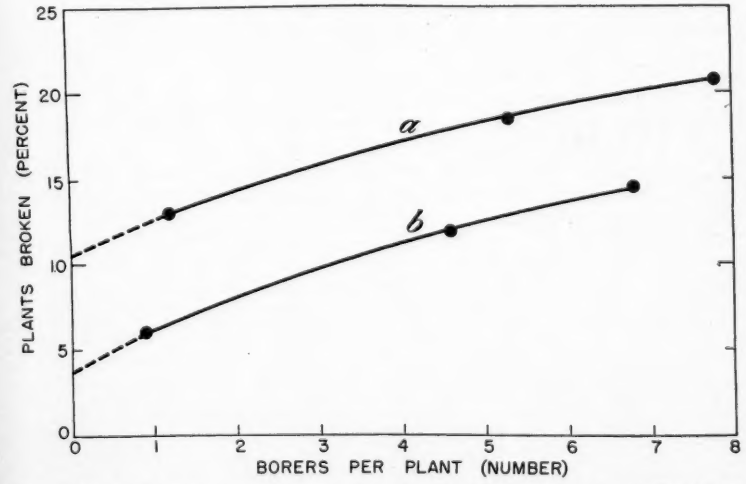

FIGURE 3.—Percentage of plants broken below the ear of open-pollinated (*a*) and hybrid (*b*) strains of corn at different levels of borer infestation.

of the hybrid plants would have been broken, and at a level of seven borers about 5.5 percent more, indicating that the hybrids were the more tolerant with respect to breakage. This was true, however, only because they stood up better without breakage in the absence of borers.

SUMMARY

The amount of injury to the quality and yield of the ears of field corn and the breakage of the stalks by infestations of the European corn borer (*Pyrausta nubilalis* (Hbn.)) were determined for hybrids and for the Clarage variety and other open-pollinated varieties in Ohio from 1929 to 1933. The various strains were subjected to different known levels of borer population induced by placing egg masses on the plants by hand. The regression of the factors studied on the borer population per plant was determined.

The reduction in the marketable yield occurred through an increase in the number of earless plants and plants bearing unmarketable ears and through a reduction in the size of the ear on all the plants bearing marketable ears.

The total reduction in marketable yield per acre per borer per plant was equivalent to the yield of about 292 hybrid or open-pollinated plants bearing marketable ears in the absence of borers. The size of the marketable ears was reduced about 2.50 percent per borer per plant in both the hybrids and the open-pollinated varieties.

On the basis of the marketable yield in the absence of borers, the marketable yield of the hybrids was reduced 2.99 percent and that of the open-pollinated varieties 3.64 percent per borer per plant. The hybrids were therefore more tolerant to the borer than the open-pollinated varieties. This advantage was due to the difference in the rate of increase per borer per plant in the number of earless plants and of plants bearing unmarketable ears per acre.

About 3.5 percent of the hybrid plants and 10.5 percent of the open-pollinated plants would have been broken below the ear in the absence of borers. Up to seven borers per plant the percentage of plants broken below the ear of both types of plants increased at the rate of about 1.47 per borer per plant. The hybrid plants therefore showed less breakage in the presence of borers only because they stood up better without breakage in the absence of borers.

In the Clarage variety 59.0 percent of all broken plants, excluding broken tassels, were broken below the ear on plants infested at levels up to 10 borers per plant.

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